TIMBER DRYING

AND

THE BEHAVIOUR OF SEASONED TIMBER IN USE

TO

MY WIFE

FOR HER HELP

TIMBER DRYING

AND

THE BEHAVIOUR OF SEASONED TIMBER IN USE

BY

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2nd EDITION

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FOREWORD (TO FIRST EDITION) AND ACKNOWLEDGEMENTS

DURING the past eleven years the author of this book has specialized in timber drying research at The Forest Products Research Laboratory, where he is now in charge of the Timber Seasoning Section. In the course of his work he has had ample opportunity of appreciating the drying problems confronting the timber users in this country. This book is intended to answer some of the inevitable queries that arise in connection with timber drying and with the behaviour of dry timber after it is put into service.

The author is very much indebted to the Director of the Forest Products Research Laboratory, Mr. W. A. Robertson, for permission to make use of data accumulated at the Labortory, and various sketches and diagrams.

Acknowledgements are also due to certain kiln manufacturers, instrument makers and others who have kindly lent drawings and photographs.

FOREWORD TO SECOND EDITION.

SINCE the first edition appeared in 1938 many things affecting timber utilization have made their presence felt.

The war called for more rapid drying and it became common practice to kiln dry from the green condition. In the previous war kiln drying was in its infancy and any sort of kiln was assured a ready sale with the inevitable result that some bad kilns were installed and kiln drying acquired a bad name, and even good kilns in the hands of incompetent or ignorant operators produced poor results. In the recent war, however, owing to the wisdom of the Timber Control, only efficient kilns were installed and nearly all operators received instruction at the Forest Products Research Laboratory. The drying of home-grown timbers from the green condition has taxed the ability of

many to the utmost. Timber is still in short supply and the avoidance of waste in seasoning is more important than ever. It is to be hoped that this book will assist in keeping down waste.

In the first edition the price of various items of equipment was quoted in the text. Owing to the uncertainty of prices today they have been omitted from this edition.

As the author is no longer on the staff of the Forest Products Research Laboratory he will not be accused of blowing his own trumpet in advising anyone who has difficulties connected with timber drying or who is contemplating installing a kiln to consult the new Director, Dr. F. Y. Henderson and the staff of the Seasoning Section under the author's successor, Mr. W. C. Stevens.

INTRODUCTION

SEASONING AND DRYING

THROUGHOUT this book the words *seasoning* and *drying* will appear frequently. It is customary to refer to the seasoning of timber and most people do not pause to think whether seasoning merely means drying or something more than drying. Probably if tackled on the point the majority would reply that some form of maturing process was implied as well as drying. This view was frequently if not universally held in the past and is largely held to this day. Yet scientific investigations have clearly shown that for all practical purposes there is no difference between one piece of wood seasoned over a period of years and another identical piece dried n a few weeks. Chemical analysis can detect slight differences, but these are so insignificant in their effects on the mechanical and physical properties of timber that they can be entirely negliected when we are dealing with timber as timber.

For the purpose of this book, therefore, the words can be regarded as synonymous and are used as such.

CONTENTS

LIST OF ILLUSTRATIONS

CHAPTER I

WHY SEASONING IS NECESSARY

MOISTURE IN WOOD—SHRINKAGE ON DRYING—STABILITY OF SEASONED TIMBER—SEASONING AND STRENGTH—SEASONING AND WEIGHT—DRYING AND ROT—APPLICATION OF PRESERVATIVES—PAINTING AND FINISHING.

ALMOST everyone realizes, in a vague sort of way at least, that timber has to be seasoned if it is to give satisfaction in service.

Probably very few people who do not actually handle timber—and quite a few who do—appreciate why it is desirable to use seasoned timber for most purposes in which wood is employed. Of course, there are certain applications where seasoning is unnecessary or even undesirable; when woodwork is constantly or frequently immersed in water, for instance, seasoning is definitely unnecessary and may be disadvantageous. But for every application of this kind there are thousands where the use of seasoned timber is not only desirable but essential if the most satisfactory service is to be obtained.

If one is to appreciate the need for drying it is helpful to understand something of the part that water plays in the make-up of timber and the way that it influences its behaviour.

Green timber, that is timber in the growing tree or in the tree immediately after it is felled, contains a very large quantity of liquid usually termed sap. Sap is very largely composed of water, and while the other ingredients have their importance both to the growing tree and to the timber obtained from the tree, we need only concern ourselves here with the water. The amount of water, or moisture, present in green timber varies very much with the type of tree, but does not vary very much from tree to tree in any one species, and—contrary to popular belief—does not alter appreciably throughout the seasons of the year. The moisture is present in green timber in two forms: It fills or partially fills the cells which go to make up the structure of wood, and it is present in the cell walls. In the former case, it is held there in much the same way that water is held in a cup; but in the latter case it is held in capillary and molecular form and cannot be removed merely by 'opening the tap'.

The amount of moisture held in the cell walls and other structural members which make up the wood substance is limited and roughly the same for all timbers—approximately between a quarter and a third of the weight of dry wood. The remaining moisture is free water.

The so-called hardwoods or deciduous trees contain moisture more or less evenly distributed across the section of the tree, that is to say, the outer rings of the tree or sapwood contain about as much moisture as the centre portion, or heartwood. Many softwoods or coniferous timbers, on the other hand, contain far more moisture at the circumference than at the centre—the sapwood holds more than the heartwood.

Fig. 1 shows pictorially the volume of water held by a log of wood. Quite a number of common hardwoods contain the same weight of water as of wood when they are green. If one takes a piece of green beech weighing, say, 20 lbs. and puts it in an oven maintained sufficiently hot to boil away all the water, it will be found to weigh only 10 lb. or thereabouts when quite dry. A very dense and heavy timber will generally contain less moisture in proportion to its weight than a light porous timber. This is only understandable when one realizes that the specific gravity of the cell walls of all timbers is practically the same and that a heavy timber is one having cells with thicker walls in

TABLE I

APPROXIMATE WEIGHT OF SOME COMMON TIMBERS WHEN GREEN, SHOWING THE PROPORTION OF WATER TO WOOD

	Weight of one cubic foot.	*Weight of water present in one cubic foot.*	*Weight of wood substance in one cubic foot.*
Ash	55 lb.	18 lb.	37 lb.
Beech	67 ,,	33 ,,	34 ,,
Birch	65 ,,	32 ,,	33 ,,
Chestnut (Sweet) . .	66 ,,	39 ,,	27 ,,
Elm (Common) . . .	70 ,	42 ,,	28 ,,
Mahogany (African) .	50 ,,	21 ,,	29 ,,
Oak	73 ,,	36 ,,	37 ,,
Scots Pine (Red Deal):			
Heartwood . .	33 ,,	8 ,,	25 ,,
Sapwood . . .	55 ,,	30 ,,	25 ,,

proportion to the cavities of the cells, consequently leaving less room for free water. Thus green oak usually contains about 80 per cent. of its own weight * of moisture, while a very light timber like balsa may contain four or five times its own weight of moisture.

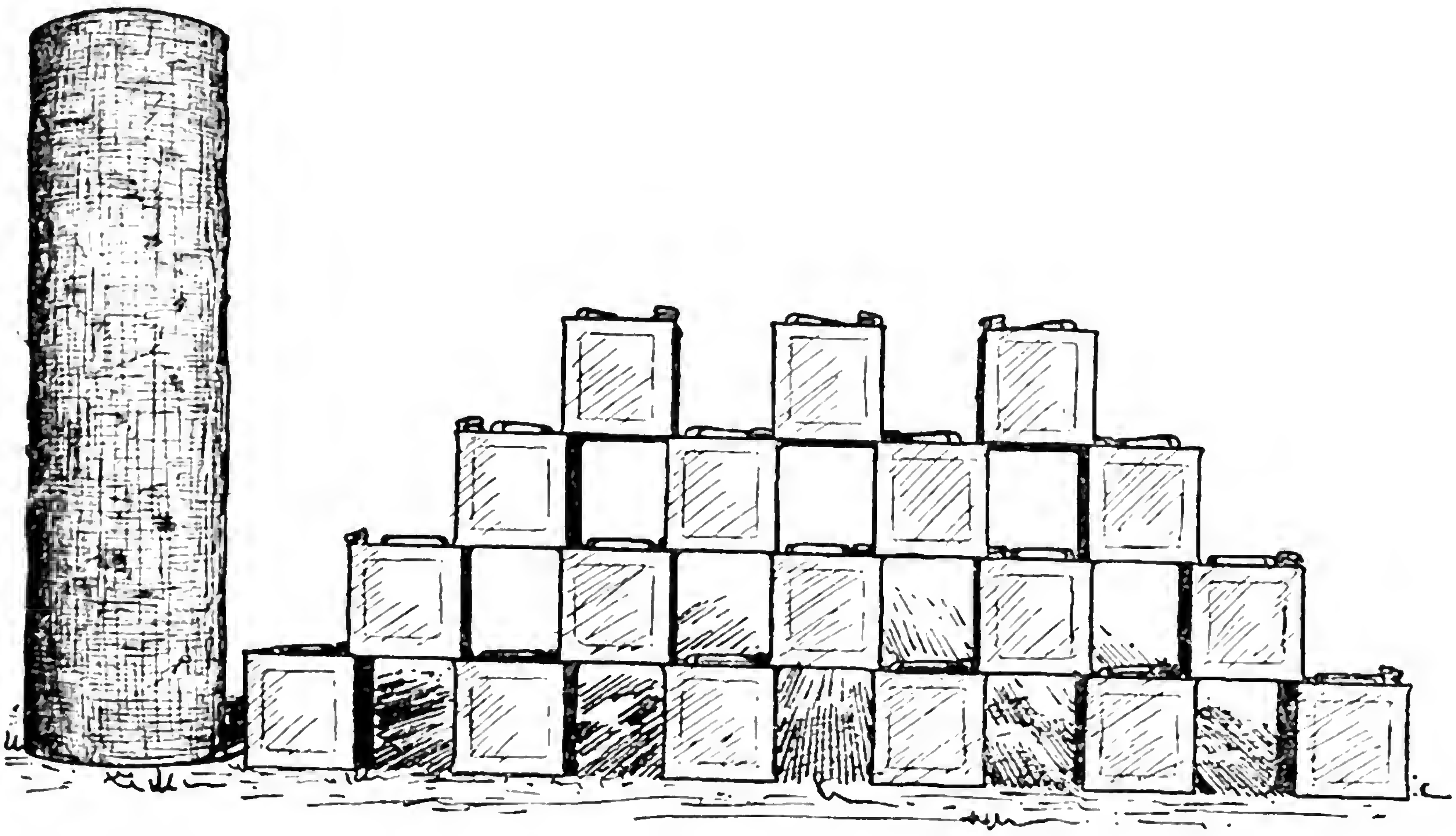


FIG. 1. Eighteen two-gallon petrol-tins would barely hold the amount of moisture contained in a green beech log 6 feet long and 18 inches in diameter. The majority of this water must be removed for most purposes in which timber is employed.

The softwoods, as stated above, often have more moisture in the sapwood than in the heartwood. A piece of green sapwood cut from a softwood tree may contain twice its own weight of moisture, but a piece of heartwood cut from the same tree will only contain about one-third of its own weight.

When a piece of timber is cut from a log the supply of water available to the tree obviously no longer exists, and the air coming in contact with the surfaces of the piece causes evaporation to take place.

The first thing that happens within the piece is that the free water in the cell cavities begins to disappear. Apart from reducing the weight, the properties of the piece of timber remain virtually unaffected. But after a time all the free water has gone

* By 'its own weight' is meant the weight of dry wood when all moisture has been removed.

and the moisture held by the cell walls begins to go too. The removal of moisture from the cell walls causes them to shrink (actually some shrinkage takes place earlier, but the amount is so small that it can be neglected for nearly all practicable purposes), and the cumulative effect of this shrinking of the cell walls is to cause the piece as a whole to shrink.

Here, then, is an obvious reason for seasoning: That all the shrinkage that is due to take place before the timber comes into equilibrium with the surrounding atmosphere may occur before the timber is manufactured and put into use; the timber must be stable, in other words.

The importance of ensuring stability cannot be over-emphasized, as unless timber is allowed to approach the condition, to which it will ultimately come, before it is finally machined and assembled, troubles in some form or another are inevitable.

If we are considering timber in its most primitive application, namely, for use as fuel, it is common knowledge that it must be reasonably dry. Also it is clear that when timber is dried and loses moisture it becomes very much lighter and can therefore be transported and handled with greater facility. From what has been stated above it must be obvious that one may be handling more weight of water than of timber when dealing with certain species in the green condition.

As moisture is removed the strength remains approximately constant until all the free moisture has gone, but thereafter as moisture is drawn from the wood substance the strength increases progressively and very considerably. Only in one respect are the strength properties not vastly increased by drying and that is in the resistance to impact. The ability of seasoned timber to withstand blows and shocks is much the same as that of green timber.

When timber rots or decays, becomes mouldy, discolours* and stains, the damage is caused by fungi. All fungi require a considerable amount of moisture for their development. Very wet timber is not generally suitable for fungal development, but the moment some drying has taken place it is susceptible to attack, and if allowed to remain in a semi-wet state, will inevit-

* It is, of course, possible that discoloration may be caused chemically without the presence of a fungus, but damage from this type of source is rare and generally slight in character.

ably decay sooner or later. Seasoned timber is, however, too dry to support fungal activity, and if kept in the seasoned state will never decay.

Dry rot in houses develops either because the timber used in their construction was insufficiently seasoned when installed, or because inadequate ventilation is provided and the timber becomes wetted from outside sources—damp rising from the ground, rain driving in, leaking pipes, &c.

If timber is to be used in damp situations it has to be treated with a preservative if it is to last for any length of time. While timbers vary very much in their power of resistance to decay, all will rot in course of time if conditions are suitable for wood-destroying fungi. Preservatives, to be effective, must penetrate the surface of the wood for some distance, otherwise they will be washed or rubbed off, or mechanical damage may expose untreated portions, thus enabling fungi to get a hold and grow from within even where a surface coating remains.

In order that preservatives may enter the wood some of the moisture must be removed. Generally it will suffice if all the free moisture is removed, but it should be remembered that partially dried wood when exposed to the sun or drying winds may split and crack and such ruptures may pass through the treated layer, leaving points of entry for fungi. Consequently, for many purposes fairly thorough seasoning is advisable before applying preservatives.

Finally, timber must be dry if it is to take paints and polishes, as very few finishes will adhere properly to a wet surface; moreover, moisture endeavouring to escape from the wood subsequent to painting, &c., is liable to cause blisters and cracking of the coating.

The reasons for seasoning may then be summarized as follows:

(1) To make the wood stable.
(2) To make it stronger.
(3) To make it lighter.
(4) To make it resistant to decay.
(5) To make it take preservatives if required.
(6) To make it take paints and polishes if necessary.
(7) To make it burn readily if that must be its fate.

CHAPTER II

WHAT HAPPENS WHEN TIMBER DRIES

MOISTURE CONTENT—DRYING FROM THE SURFACE—UNEQUAL SHRINKAGE—WARPING—UNEQUAL DRYING—DRYING STRESSES—CASEHARDENING—SEASONING DEFECTS. SHAKES, SPLITS, KNOTS, INTERNAL CHECKS, COLLAPSE—MOISTURE IN THE AIR AND ITS RELATION TO TIMBER—DANGER FROM FUNGUS ATTACK IN DRYING.

In the previous chapter the presence of moisture in timber was referred to and some indication was given of the effect of the removal of moisture. It was further stated that when all the free moisture had gone shrinkage sets in.

Before going further into the manner in which shrinkage occurs it will be well to get used to referring to the amount of moisture present at any given stage in a way easy to express and in the manner rapidly being adopted in the timber trade and among timber users generally.

The amount of moisture in timber is conveniently described as the weight of moisture present expressed as a percentage of the weight of dry wood remaining when all the moisture has been removed. This quantity is known as the percentage moisture content.

The beech log in Fig. 1 contained as much water as wood, therefore its moisture content was 100 per cent. If half the moisture present was removed the moisture content would fall to 50 per cent., if three-quarters was removed to 25 per cent., and so on.

In practice, the moisture content can be determined in a number of ways, and these will be described later. The simplest and certainly the best way—though not the quickest or necessarily the most economical—is actually to cut a small piece of wood out of the timber to be tested and weigh it. When the weight has been recorded the piece is placed in a ventilated oven maintained at the temperature of boiling water (100° C., 212° F.) and left there until it will dry no more. To ensure that the piece is dry a trial weighing is made after some hours, and if no change in weight occurs after a further period in the oven, it may be assumed that the oven dry weight has been obtained.

The initial weight (W) minus the dry weight (D) represents the amount of moisture which has been evaporated. The weight of moisture originally present divided by the dry weight of wood multiplied by one hundred gives the moisture content per cent. Or expressed in another way, and in symbols:

$$\frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Dry Weight}} \times 100 = \text{Moisture Content } \%$$

or

$$\frac{W - D}{D} \times 100 = \text{Moisture Content } \%.$$

Fig. 2 shows the sequence of operations to be performed. It will be noticed that the test piece is not taken right from the end of the plank being tested, but some 6 to 9 inches away from the end. This is because timber dries faster through the end grain than in other directions, and a test made right at the end might give a lower moisture content value than that of the plank as a whole.

Some numerical examples of moisture-content determination may serve to make the operation completely clear:

Example 1. Wet weight of test piece $= 1\frac{1}{2}$ lb.
Dry ,, ,, ,, ,, $= 1$ lb.

Therefore Moisture Content =

$$\frac{1\frac{1}{2} - 1}{1} \times 100 = \frac{\frac{1}{2}}{1} \times 100 \times 50\%.$$

Example 2. Wet weight of test piece $= 0{\cdot}78$ lb.
Dry ,, ,, ,, ,, $= 0{\cdot}57$ lb.

Therefore Moisture Content =

$$\frac{0{\cdot}78 - 0{\cdot}57}{0{\cdot}57} \times 100 = \frac{0{\cdot}21}{0{\cdot}57} \times 100 = 36{\cdot}8\%.$$

If it were possible to dry all parts of a piece of wood at the same rate, no appreciable shrinkage would take place until the moisture content had fallen to somewhere between 25 and 30 per cent., when the piece would begin to decrease in size until drying ceased.

The only practicable methods of seasoning at present known involve drying from the surfaces of a piece of timber. This means that the surfaces exposed to the air must inevitably dry

faster than the interior portions of the wood. This in turn means that the surface will begin to shrink before the centre and as long as drying proceeds will have shrunk or will have endeavoured to shrink more than the centre.

Here we have one reason for the difficulties encountered in the drying of timber. We will return to this in a moment, but before going further, some discussion of a still greater difficulty may be of value.

When a block of timber dries it does not become smaller by equal amounts in all directions; its shape changes. This is because shrinkage is not the same in the different grain directions.

The greatest shrinkage occurs in a direction tangential to the growth rings (the annual rings)—looking at a cross-section of the tree. The shrinkage in a direction from the centre of the tree outwards, or radially, is nearly always considerably smaller than the tangential shrinkage, whilst the shrinkage along the grain, that is along the length of the tree, is very small indeed and can nearly always be neglected.

It will be seen at once that this being the case, all sorts of complications arise when timber dries. When it is further appreciated that the grain of the tree is hardly ever absolutely straight —or if it is, the piece cut from it may not necessarily be cut truly along the grain—it is evident that some effect of the radial or tangential shrinkage may also be felt in the longitudinal direction as well. Expressed mathematically, it may be said that a component of the radial or tangential shrinkage forces may act along the grain.

The difference in shrinkage along the three directions is practically entirely responsible for all the warping that occurs in timber. Other minor forces responsible are mechanical deformation due to bad piling during drying, forces present in the growing tree which are released when timber is cut from it, and unequal drying—which is, of course, tied up with shrinkage, but is not necessarily due to differential shrinkage in so far as the various grain directions are concerned.

Referring to Fig. 3, let us consider how shrinkage affects the plank *A*. This plank is what is known as a 'plain-sawn' or 'flat-sawn' plank, that is to say, the log has been passed backwards and forwards through the saw so that all the cuts are parallel to

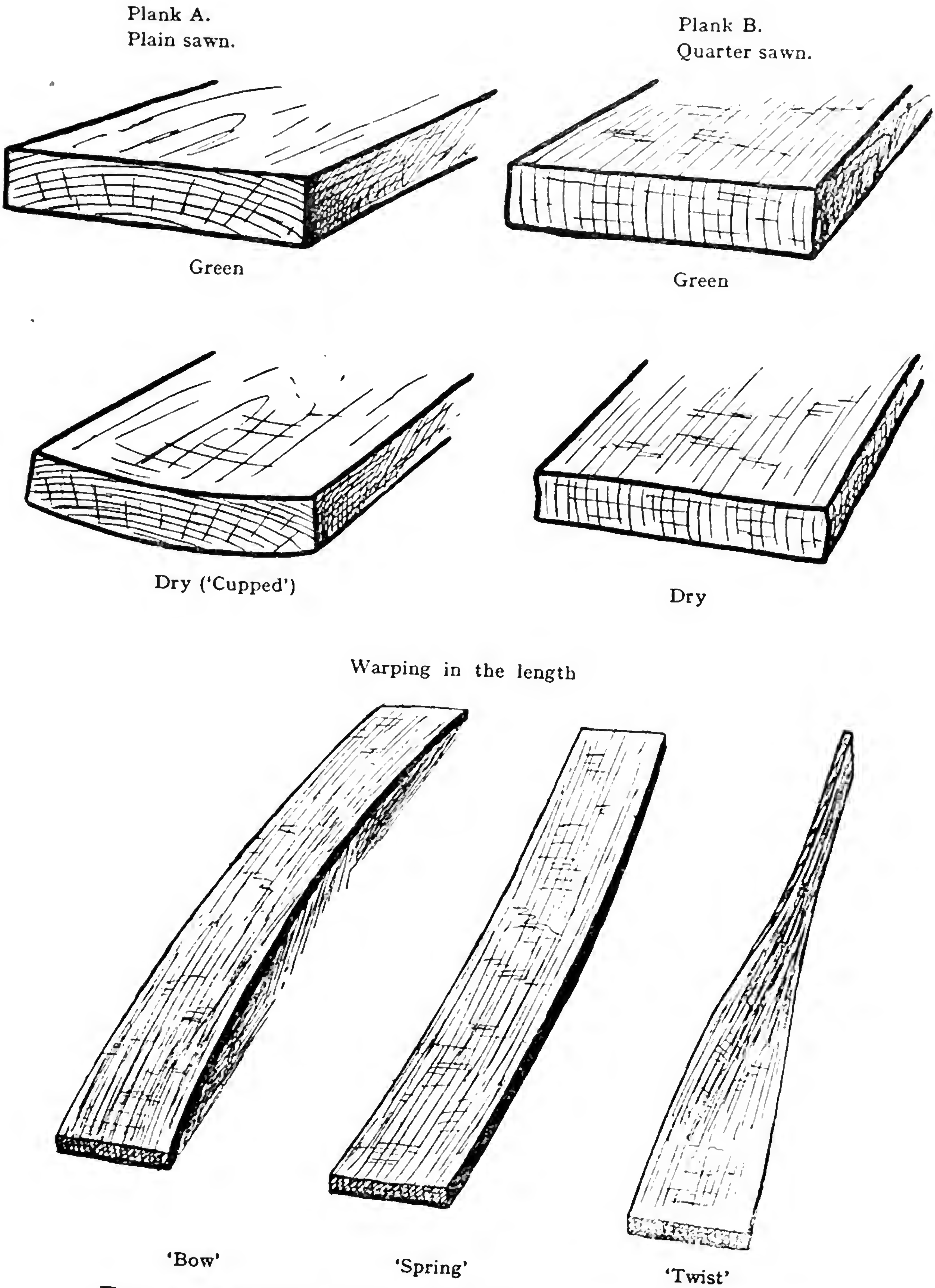


FIG. 3. Distortion of sawn timber caused by shrinkage.

one another. Plank *A* has come from near the outside of the log, so that the annual growth rings are running approximately parallel to the face of the plank. The greatest shrinkage will therefore be in the width of the plank; that in the thickness will be roughly half over the same distance, while that in the length will be very small indeed. The top side of the plank—the side farthest from the heart of the tree—will shrink more than the bottom side because the annual growth rings adjacent to that side are more nearly parallel to it than those near the bottom side are to it (the bottom). In other words, the top side experiences more nearly the full tangential shrinkage, whereas the shrinkage at the bottom is a mixture of radial and tangential shrinkages.

It therefore follows that as the plank dries it tends to become concave on the top side, which in turn tends to make it convex on the bottom side. If the difference between the radial and tangential shrinkage is large, and the size of the tree small relative to the thickness of the plank, it may well take up the shape shown in the figure when dry.

If the grain is crooked or twisted or is not truly parallel to the axis of the plank, this distortion effect produced by the radial and tangential shrinkages pulling one against the other will also be apparent in the length, causing one or other or a combination of the various forms of longitudinal warping shown at the bottom of the figure.

On the other hand, if a plank is cut 'on the quarter', as plank *B*, so that the annual growth rings run across the thickness, little distortion will take place in the section of the plank as it dries, though the edges may be slightly affected since they are now in the same case as were the sides in the plain-sawn plank we have just considered. Distortion in the length may, of course, occur to the same degree as in the plain-sawn plank. The quarter-sawn plank remains practically the same shape because the shrinkage on the two faces is approximately radial in each case, and in any case because the radial shrinkage is smaller than the tangential, the difference in shrinkage between the two sides is also smaller.

The nett shrinkage in the width is obviously smaller than in a plain-sawn piece, but the nett thickness shrinkage is greater. Obviously a quarter-sawn plank is to be preferred from the dry-

ing aspect, but it is much more costly to saw in this manner as the log has to be turned for each cut and the percentage of waste in converting is greater.

Returning now to the practical process of timber drying, we find that we are obliged to dry from the outside and that when we do this shrinkage will take place beginning with the outside layers and by different amounts in the different grain directions.

Fortunately, most timbers are fairly tolerant of some abuse; we can dry the outside layers quite appreciably in advance of the centre portion without splitting the wood. In other words, there is some 'give' before rupture takes place. The art of successful drying lies in knowing exactly how much abuse may be used without causing mechanical failure.

In addition to the annual rings, another structural feature visible on a good many species of tree are the medullary rays which radiate from the centre of the tree outwards. Moisture passes most readily along the length of the tree, but it passes more readily in the direction of the rays than along the direction of the rings. Consequently a plain-sawn board having numerous rays leading to the surface dries more rapidly than a quarter-sawn board having few. On the other hand, the rays are a weak point in the structure and timber will split along the rays in preference to any other way, therefore a plain-sawn board is more likely to split in drying than a quartered board.

Assuming that drying is not so severe that splitting actually takes place, let us consider what happens: The greater tendency to shrink of the outer layers is resisted by the centre portion, and therefore a state of stress develops in which the outer layers are being pulled and the inner are being compressed.

If this state of affairs is allowed to become too severe—and yet not sufficiently severe as to cause splitting—the wood accommodates itself to the conditions by stretching of the outside and squeezing of the inside. As the outside layers dry they become harder and stronger and may set in this stretched state. When the inside dries out in turn it too becomes stretched, since the unnaturally extended outside—now dry and strong—prevents it from shrinking the normal amount. What happens then ? The stresses imposed are now reversed; the outside layers are now being pulled in by the inside portion which is being stretched.

This state of affairs, very common in dry timber, is known as **Casehardening.** Casehardening is a term much used in the timber trade, and is often imperfectly understood. From what has been written above it must be evident that it is impossible to dry timber without imposing slight drying stresses at least, but these stresses gradually disappear as the timber becomes uniformly dry, unless they are allowed to become very great at some time. If casehardening develops it will remain in the dry timber—and unless relieved by artificial or natural means, as will be described later—may persist for months or even years, or the life of the timber. Casehardening stresses are dangerous, because timber is hardly ever left in the form in which it is dried. Some machining operation is nearly always performed subsequent to the seasoning process. Directly some portion of the wood is removed, or some cut is made, the balance of stresses may be disturbed, and in attaining a new balance the shape of the piece may be altered. Warping may occur through cutting a piece of casehardened dry timber, just as it may occur in drying green timber.

It was shown above that when a piece of casehardened timber was quite dry the stresses present were in the form of compression of the outer layers and tension of the centre portion. If a casehardened plank is sawn down the middle into two boards, these may become concave on the new face as the original outside layers push outwards and the centre pulls inwards. This is made use of to determine the extent of casehardening stresses present as shown in Fig. 4. If a piece of casehardened wood is planed, one side may be planed more heavily than the other, thus upsetting the balance and leading to possible 'cupping'. We have considered above how shrinkage may cause warping, and more recently we have dealt with the internal stresses produced as a result of unequal shrinkage. These stresses are responsible for most of the other defects which may develop when timber dries.

The growing tree often acquires faults in the structure which may be brought about by disease, storms or other more obscure causes. These faults frequently take the form of actual rupture of the timber and are visible when the log is sawn up into boards and planks. When a split is present in this form it is clearly very likely to open and extend when drying stresses are imposed.

The heart of a tree nearly always contains defects of some sort or another and consequently it is not surprising to find that a plank containing the heart and pith often develops serious splits as it dries out. These splits associated with defects present in the

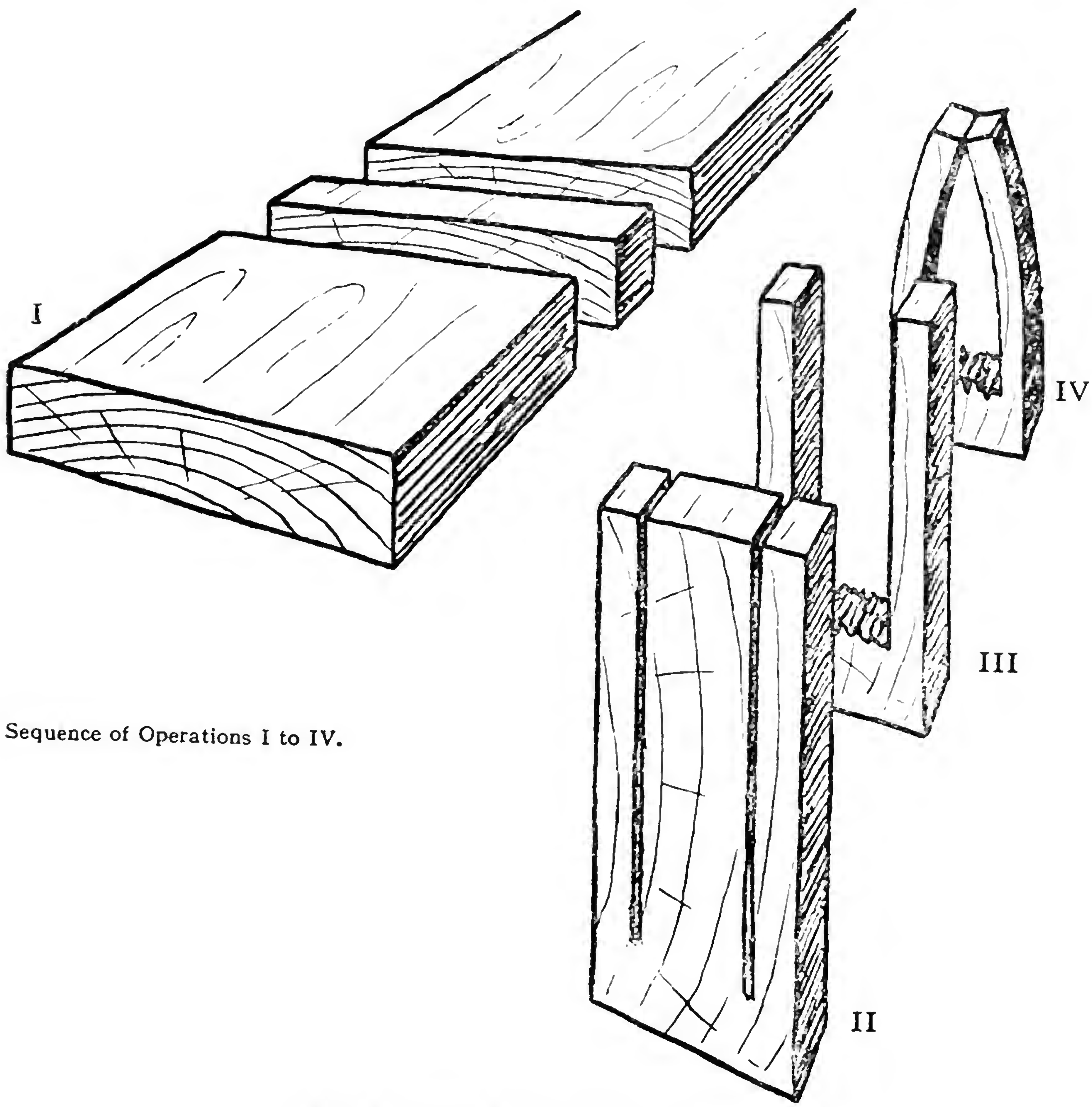


FIG. 4. Test for Casehardening.
I. Cut a section as for moisture determination.
II. Make two saw cuts in the section.
III. Chip out the centre portion.
IV. If the prongs spring in the timber is casehardened.

living tree are usually referred to as 'heart shakes' or 'shakes' (Fig. 5). If a shake opens out and extends on drying it is hardly likely to be confined to its immediate vicinity, but will tend to follow the grain and may eventually run from end to end of the piece containing it. For this reason many sawyers make a prac-

tice of sawing through the middle of any plank containing the heart, or a bad shake. Then as the shake spreads it will be confined to the edges of the planks obtained from either side and is less likely to travel across the plank, rendering it practically useless when dry.

Probably the most familiar form of fibre rupture in timber is the splits which occur at the ends. As explained previously, timber dries most rapidly through the end grain, and therefore the area adjacent to the ends tends to shrink before the timber as a whole. It is prevented from doing so as a unit, however, and so accommodates itself by shrinking locally, splitting up into several areas. The splits so formed are known as end splits or end checks (Fig. 5).

The end splitting of logs is very common, because not only is this end-drying effect at work but also the forces introduced by the difference in radial and tangential shrinkage are in operation.

Surface splits or checks are caused, as we have seen under Casehardening, by the breakdown of the surface fibres under the stresses imposed by too rapid drying of the surface relative to the centre.

Later we shall consider how internal splits may be caused through casehardening.

Knots are responsible for a number of drying defects. As they usually run approximately at right angles to the grain of the tree, it follows that they will shrink least (longitudinally) where the parent piece shrinks most (radially or tangentially), and vice versa. A protuding knot is quite common in dry timber because it has hardly shrunk at all in its length, while the surrounding timber has shrunk considerably in a radial or tangential direction or a combination of the two. Split knots often occur because they are subject to the same influences as the ends of logs. Loose knots develop when they are caused by dead branches in the living tree, so that the tree as it grew round them has never been intimately connected with them. Moreover, resinous timbers coat wounds and foreign bodies—and a dead branch can be regarded as both—with a liberal supply of resin to disinfect the area, and in drying the resin may exude, leaving the knot loose.

It will be seen that there is always a tendency for a knot to become separated from the main piece in the direction of the

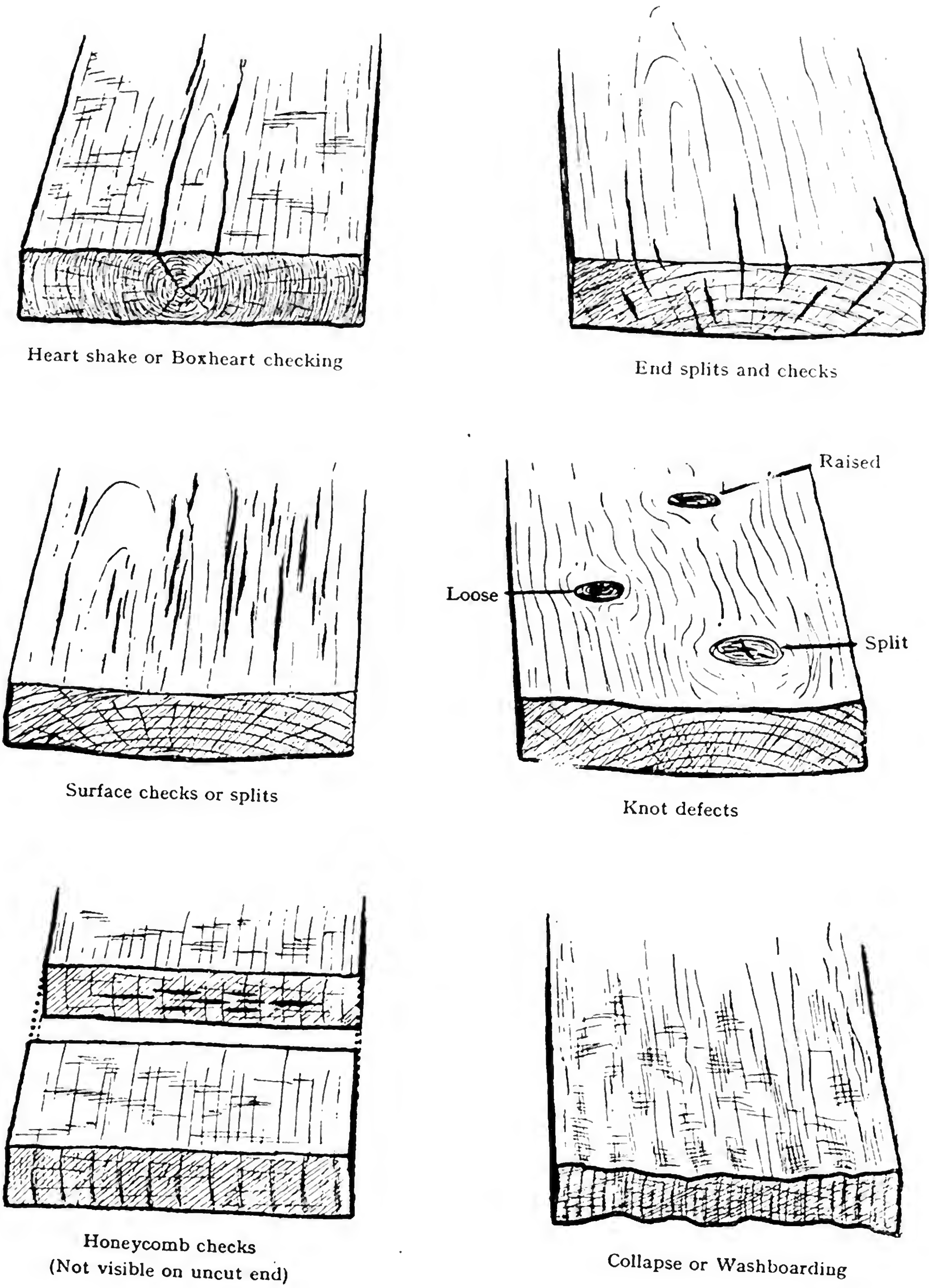


FIG. 5. Seasoning Defects.

grain of the piece, since the knot shrinks radially, and therefore appreciably in this direction, whereas the main piece hardly shrinks at all along the grain. Another contributory cause is the fact that knots tend to be denser in structure than the tree in which they grow and the shrinkage of timber is roughly proportional to the density.

Knots—particularly large ones—are an endless source of trouble in drying, because apart from what may happen to them the growth irregularities caused by their presence, twisted grain and the like, mean unusual local shrinkage and distortions.

In the same way that it is advisable to cut out large shakes when sawing the timber, so it is a good plan to cut away as many large knots as possible.

When discussing casehardening we saw how it is possible for the centre of a piece of timber to become stretched as a result of the hard, dry outer layers which had become set in an expanded state. It may happen that the timber is unable to support this stretching process and rupture occurs. In that case internal splits or honeycomb checks will develop (Fig. 5).

Lastly, one more form of seasoning defect is sometimes found: Collapse or washboarding (Fig. 5) may be caused through the timber shrinking more over a certain portion of growth rings than at another (possibly due to varying density), or through actual collapse of the cells themselves. Collapse of the cells is not fully understood, but it is believed that it may be due to the enormous forces produced by surface tension when water is withdrawn from the cell cavities. Genuine collapse can be removed to a large extent by a process known as reconditioning (see page 111).

So far we have assumed that we have been able to dry timber by some means or other, and have considered the result of the removal of moisture in so far as it produces shrinkage; how in turn shrinkage causes warping and produces stresses which may cause splitting in various forms.

In the next two chapters we shall be dealing with the two recognized ways of seasoning timber: by natural means—or air-drying, and by artificial means—or kiln drying. Since there is much in common between these two methods, it may be as well to consider some aspects here.

I

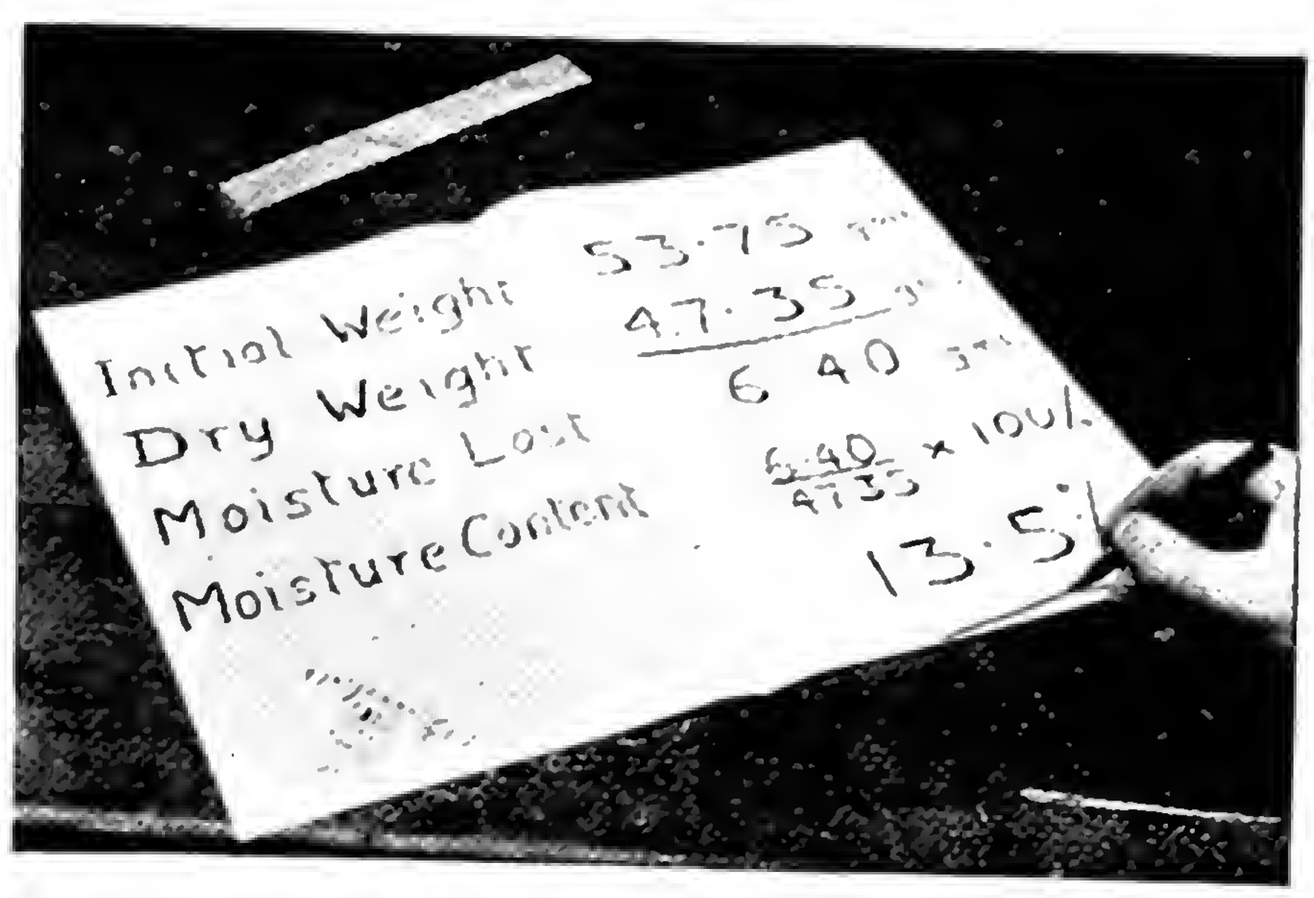
Remove the dry end of the board before cutting the moisture-content sample.

II

Weigh the sample as soon as possible; this is the *Initial Weight.*

III

Keep the sample in an oven at boiling-point until it attains *Dry Weight.*



IV

Working out the result.

(Courtesy of Forest Products Research Laboratory)

FIG. 2. Moisture content determination by the oven-drying method.

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(Reproduced from Fig. 4. Forest Products Research Bulletin No. 9 'Home Grown Pitprops' by permission of the Controller of H.M. Stationery Office

FIG. 6. Piling poles for drying.

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In all methods of drying at present within the realm of practical politics, air is used to evaporate moisture from the surface of the timber and to convey it away.

Ordinary atmospheric air is nearly always capable of taking up more moisture than it contains already. We may talk about the air being humid or dry, but we do not mean by that that it is absolutely saturated with moisture or completely devoid of it. The terms are relative. Atmospheric air always contains a considerable amount of moisture, particularly in this country. If it contains all the moisture it can hold it is said to be saturated, or the relative humidity is said to be 100 per cent. Similarly, if it contains only half the amount of moisture it can hold, the humidity is said to be 50 per cent. The actual weight of moisture held varies very much with the temperature, but the rate at which air will take up or evaporate moisture is much more dependent on its humidity than its temperature. In this country the relative humidity of the air generally lies between 60 and 80 per cent., being drier in summer than in winter. This means that a piece of wet timber placed so that the air can circulate freely about it will lose moisture by evaporation until a state of equilibrium between the moisture in the surface layers of the timber and the moisture in the air is established. As moisture is evaporated from the surface of timber its place is taken by further supplies flowing or diffusing from the interior, and so the process goes on until the whole piece of timber is uniformly dry and in equilibrium with the air. The amount of moisture remaining—or the moisture content of the timber eventually attained—will depend on the humidity of the surrounding air. Thus a piece of timber in equilibrium with outside air in winter will dry further when summer comes along. Conversely timber completely dried in summer will re-absorb moisture when the more humid air of winter comes.

This question of equilibrium between air and timber is a very important one and we shall be returning to it later, but it must be left for the moment to consider yet another cause of possible damage to timber as it dries.

It was stated in Chapter I that one of the reasons for drying timber was to render it immune from fungus attack. Unfortunately as it dries it is particularly susceptible to fungal development, because it must pass through a stage when the

amount of moisture present is that most attractive to fungus. Fortunately, most of the wood-destroying fungi do not develop rapidly, so that the timber is dry and no longer suitable before much damage can be done. But many staining fungi grow very rapidly, and if conditions are right it is possible for almost complete discoloration to take place in a few hours. Moulds which grow so readily on moist timber do not penetrate the surface, but their presence may retard drying by keeping the air away.

Methods of avoiding fungal staining are discussed later, as are the rarer forms of staining due to chemical action alone as distinct from fungal attack.

CHAPTER III

THE AIR-DRYING OF TIMBER

DRYING IN THE LOG—SEASONING POLES AND ROUND TIMBER—STACKING SAWN TIMBER FOR DRYING. PILING IN LOG FORM. PILING EDGED TIMBER. THE SITE. FOUNDATIONS. PILING STICKS. ROOFS. SIZE OF PILE. PILING. LAYOUT OF PILES.—STACKING SPECIAL SIZES—CONTROLLING THE SEASONING PROCESS—PREVENTING SPLITTING AND STAINING—GAUGING THE PROGRESS OF DRYING—DRYING TIMES—NOTES ON THE AIR-SEASONING OF COMMON TIMBERS—LIMITATIONS OF AIR-SEASONING.

TIMBER has been air-seasoned since time immemorial and it is safe to assume that this method of drying will be practised as long as any timber remains in the world. But it will be practised less and less as time goes on, as methods of so-called artificial drying improve, as the price of the raw material goes up, and property rents increase. Air-seasoning is often referred to as 'natural' seasoning, but the term is a misnomer as there is nothing more natural about cutting timber up and piling it in an orderly fashion than there is in placing it in a heated chamber. It is a pity that the term 'natural' has become associated with air-drying because it suggests that kiln-drying is *per contra* 'artificial' and therefore in some way harmful. Yet the process is essentially the same whichever method is employed. In both cases air is circulated through the pile of timber—with this difference: in air-seasoning the air is the prevailing atmospheric air, in kiln-seasoning the air is conditioned to suit the timber.

The great merit of air-seasoning lies in the fact that no special apparatus is required. Anyone can air-season timber in his back yard. But when you have said this for it you cannot say much more. The process is not necessarily cheaper, though it usually is as things are at present.

Later we shall discuss the aspect of air-seasoning *versus* kiln-seasoning further, but at the moment we shall concern ourselves with methods of air-seasoning and details of procedure in order to obtain the best results.

If a tree is felled and left to lie in the forest, will it dry ? If the tree is small, and the trunk is not resting on the ground, the answer is: Yes, in time, after a fashion. If a tree is a normal-

sized one, that is of a size large enough to be sawn up into boards, planks and scantlings, very little drying will take place, and that will be confined to the outer layers and the end where it was felled. Moreover, as the tree lies in the forest it will be open to attack from fungi and beetles and will almost certainly become practically worthless long before it is even partially dried.

A small tree—suitable for a telegraph pole, for instance—seasons fairly rapidly if kept clear of the ground and if the bark is removed when the tree is felled. Softwoods are usually employed for poles because they grow straight and have no branches to speak of. Now it will be recalled that the bulk of the moisture in most softwoods is contained in the sapwood. As this lies nearest to the air it follows that softwood poles dry sufficiently in a relatively short time.

The following assertion can be made, however: If a tree is destined to be sawn up, the sooner this is done after felling the better. Nothing but harm can come from leaving timber in the log. Of course, it is often convenient to leave logs in that form until it is known in what manner it will be expedient to saw them, and so on, and with a good many species of timber this practice is not harmful provided the logs are kept in a reasonably dry place and the ends are protected from wind and sun.

But let no one think that 'seasoning in the log' is anything more than leaving it in the green condition at the mercy of a whole host of parasites. Recent research has indicated that there is one advantage in leaving certain species of timber in the log for a year or so. Timbers which are susceptible to attack by the *Lyctus* or Powder Post Beetle when dry are probably rendered immune by leaving in the log for some time prior to drying. The starch contained by the living tree, which is attractive if not essential to the *Lyctus* beetle, becomes gradually depleted if drying is delayed.

Small trees destined for use in the round as poles and the like should be peeled soon after felling to accelerate drying and to reduce the risk of fungus and insect attack. They should then be stacked in the manner shown in Fig. 6. If piled in this manner poles up to, say, 6 inches in diameter put out to season early in the year will dry sufficiently in about six months. If piled in early winter rather longer will be required, and they

will probably not be sufficiently dry before those put out to dry in the following spring. Less splitting will occur, however, since the timber experiences relatively slow drying conditions in the early stages. Needless to say, the above remarks apply to this country and temperate climates.

Round timber is seasoned to make it stronger, lighter, more resistant to fungus attack—or if to be treated with a preservative to make it dry enough to take the preservative. These are the primary considerations. Warping and splitting are of small account, generally speaking. Splitting may even be an advantage since preservatives can be introduced through the cracks. Therefore the main object in piling the timber is to secure free passage of air to all parts. It will be seen that the method of stacking shown in Fig. 6 secures this. Alternative layers contain only a few poles, so that the air can blow through the stack with a minimum of obstruction. The poles only touch where they rest on one another, and as they are round in section they touch at one small point only. The bottom poles are kept clear of the ground which has previously been cleaned of weeds and grass. There is no need to build a roof over the stack, as rain drains through readily and any wetting of the timber is superficial and soon evaporated.

The method of stacking sawn timber for air-drying depends considerably on the sizes to be dried and on the ultimate use to which the timber is to be put.

If it is convenient to leave the edges of the boards or planks untrimmed—as in the chair-making industry, for instance, where legs and other parts are sawn out to a curved shape so that advantage can be taken of the natural curves of the trunk —then the best plan is to pile in the manner shown in Fig. 7. This is known as piling in log form. The bottom logs should be kept well clear of the ground, which should be free from weeds and rubbish of all kinds. In order to make a firm base on which to pile the logs above, the slabs, that is the pieces cut off in the first and last saw-cuts, are discarded, but they are retained for the top logs to act as a form of roof. As this form of piling almost inevitably leads to a more free circulation of air than when a proper rectangular pile is constructed, it should be remembered that drying will be more rapid and precautions may be necessary to prevent it becoming too rapid.

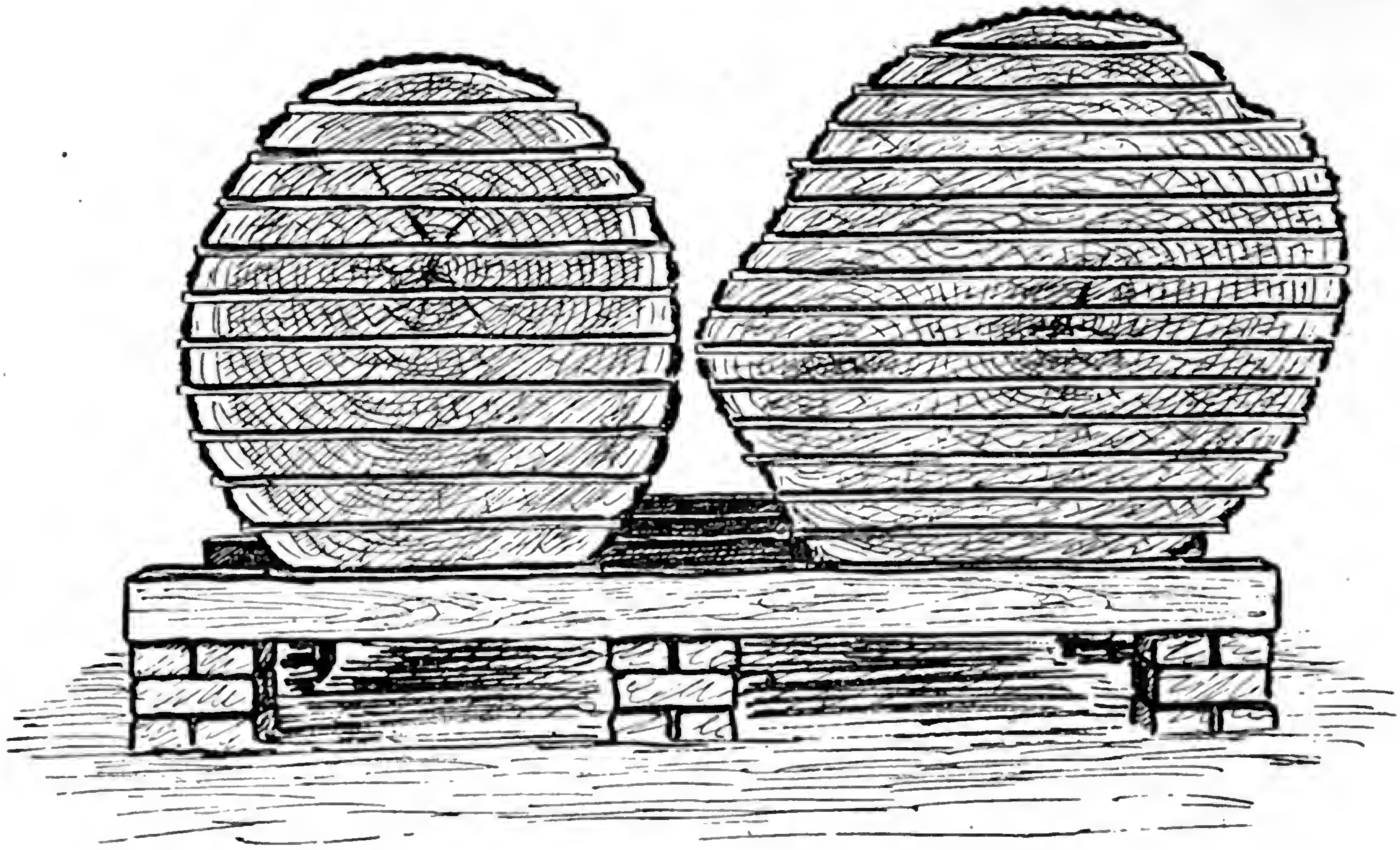


FIG. 7. Piling in log form.

All square-edged sawn timber—other than special sizes such as sleepers, furniture squares, &c.—should be stacked in the manner shown in Fig. 8. The fact that the edges are trued up simplifies the construction of an orderly stack, though unedged timber can be piled in this form too instead of in log form.

As there are several points to be observed in constructing an air-seasoning pile on these lines it may be as well to deal with them separately and in some detail.

The Site. The site should be level, well-drained ground, not too near buildings and trees. All weeds and grass should be removed—the turf actually dug up and taken away—and if possible a layer of ashes spread.

Foundations. Many forms of foundation are possible, but probably the most convenient is the type shown in the diagram. Piers of bricks are easily constructed, are reasonably firm and can be used again if required in a different position. Each pier should be about three to four courses high, consisting of six or eight standard-sized bricks. The piers should be laid in three lines, at 2-feet centres, i.e. 1 foot 3 inches from corner to corner.

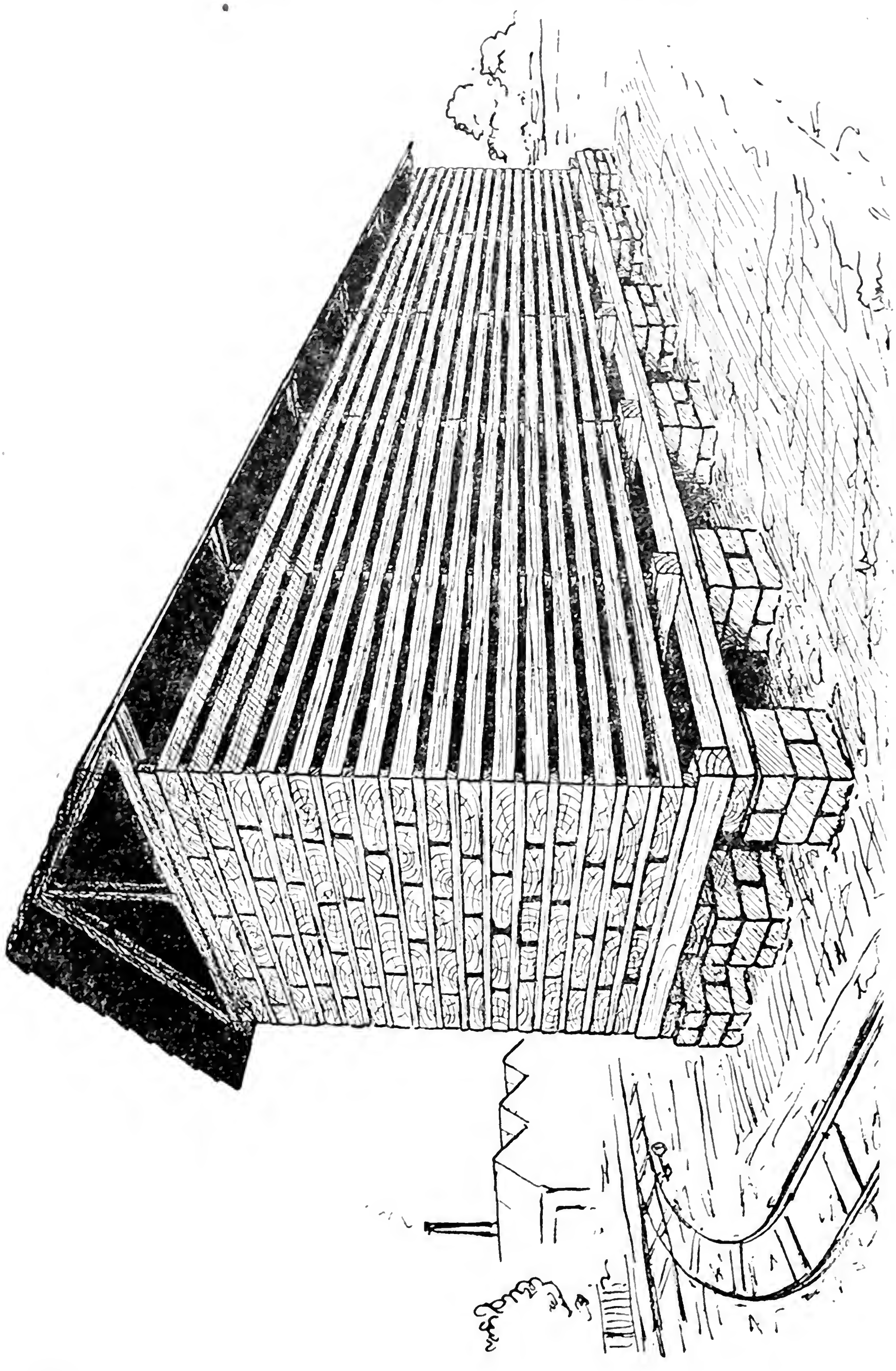


FIG. 8. Air-seasoning stack.

Three longitudinal timber members about 2″ × 9″ in section, well creosoted, should be laid on the three rows of brick piers. Any levelling required can be done by placing creosoted wooden packing blocks between the bricks and the members. Creosoted cross members of not less than 4″ × 4″ in section should then be laid over the longitudinal members. The spacing of these cross members will depend on the spacing desirable for the piling sticks or strips, but in any case should not exceed 2 feet.

A good foundation is highly desirable in order to keep the timber well clear of the ground so as to allow of ample ventilation beneath the pile. If damp air accumulates beneath the pile it will encourage fungal development, and it must be remembered that the air is often alive with fungus spores. It is hopeless to try and keep the spores from the timber; the only thing that can be done is to make conditions unattractive to them.

The brick piers insulate the timber from the ground so that fungi growing in the soil cannot easily reach the timber above.

Concrete piers instead of bricks, and old rails instead of timber bearers are even better, but they are more expensive and less easily altered to another position.

A strong level foundation like that described ensures too that there will be no tendency to distort the timber mechanically.

Piling Sticks. Except in special cases to be dealt with later, piling sticks should always be employed to separate the layers of timber. Using some of the boards or planks as separators is bad practice, because practically all air is kept away from the comparatively large areas of contact. This means slower drying at these points and more opportunity for fungi to grow. Also if the unseasoned timber is used in this capacity it will shrink and may warp and so upset the pile, causing more warping in the pile as a whole than would occur if dry material was used. Piling sticks are best cut from well-seasoned deal boards to various dimensions for different purposes. Generally speaking, two sizes of stick will meet most requirements: 1″ × 1″ and ½″ × ¾″ in section. The length is obviously governed by the width of the pile, which should not exceed 6 feet.

As stated above, piling sticks should not be spaced more than 2 feet apart, but are sometimes spaced as little as 9 inches apart. Between these two limits the spacing adopted will depend on the

thickness of the timber and its liability to warp. Timbers containing much twisted grain and having a big difference between radial and tangential shrinkage call for sticks at frequent intervals. Thus $\frac{3}{4}$ inch thick elm coffin-boards are best stacked with sticks at 9 inch centres, while 3 inch thick deals can quite well be stacked with sticks 2 feet apart. It should be realized that the function of the piling sticks is not only to separate the timber so that air can circulate freely, but actually to restrain some of the warping liable to occur as a result of the natural shrinkage of the timber in drying.

Roof. If the pile is erected under cover, obviously no sort of additional roof is called for, but in the open air some overhead protection is highly desirable. A rain-tight roof is not necessary, but some means of keeping off the heavy rain and the fierce heat of the mid-day sun is strongly recommended. A weather board roof of the type shown in the diagram is very suitable and reasonably cheap. A good fall to one side, to throw off heavy rain, should be provided, and a fairly generous overhang on all sides shades the pile to some extent and prevents water dripping from the roof being blown into the pile. The roof is secured to the pile by ropes or wire fixed to piling sticks some way down, or to the foundation bearers.

Size of Pile. The only dimension which is limited in deciding on the size of a stack is the width. As stated above, this should not exceed 6 feet. Experiments have shown that air cannot pass readily through a stack wider than this as a general rule. The length is obviously governed by the maximum length, or multiple of the length, of the timber to be seasoned. The height is limited only by the facilities for stacking the timber and by consideration of stability—not forgetting the wind.

Piling. When piling the timber, sticks should be laid on all the cross bearers which must be previously spaced to suit the arrangement of sticks to be adopted. A layer of boards or planks can then be laid on the sticks, taking care that no sticks are displaced in the process. About 1 inch should be left between adjacent boards or planks so that the air can pass vertically through the pile as well as horizontally. If this is not done, not only will drying be slower in the centre of the stack, but there

will be a tendency for moulds to grow on the edges. Moreover, any rain penetrating the stack will be partially trapped. Another lot of sticks can then be laid. Particular care should be taken to see that they lie vertically above the sticks below. This is most important as the weight of the stack will be inclined to distort the timber if not transmitted from stick to stick in vertical alignment. It is obviously particularly important if the timber is thin and has therefore little strength.

And so the pile can be built up until the last row is put on. The roof is then put in position, the trusses being so placed as to come immediately above a line of piling sticks. If several different thicknesses of timber have to be built into the same stack, for obvious reasons the thicker material should be placed at the bottom.

Layout of Piles. There appears to be little or no advantage in placing timber stacks in any particular way with reference to the prevailing wind, adjacent buildings, &c. It is important, however, that the stacks should all lie in the same way. Provided a space of one foot is left between adjacent stacks, any number can be built side by side. Spacing in the longitudinal direction is not required from the drying aspect, but will be needed to enable stacks to be built and taken down without undue congestion, particularly if only a foot or so has been left between adjacent stacks in the other direction.

Certain kinds of material which are cut to standard sizes can be piled without the use of sticks. Sleepers, for instance, must perforce be stacked in some manner involving a minimum of space and cheapness in piling. The method shown in Fig. 9 is an excellent compromise, because by that means air circulates freely to all parts and a compact pile one sleeper length long by one sleeper length wide is obtained. Sleepers have ample mechanical strength to enable high stacks to be built in this fashion; a method obviously inapplicable to thin boards. It will be noted that there is practically only line contact between one sleeper and another so that no appreciable area is shielded from the air. Again, sleepers are almost entirely cut from free-drying softwoods which are tolerant of severe seasoning conditions. With this method of piling the air circulation might well be too excessive for refractory hardwoods.

Small furniture parts like chair-leg squares, chair rails and similar so-called small-dimension stock can be piled in the manner shown in Fig. 9 (at the top). Here the pieces themselves are so small that they can be used in place of piling sticks without fear of restricting the air unduly, or on the other hand, ventilating the pile excessively. The pieces used as piling sticks should be treated as such, kept in vertical alignment and

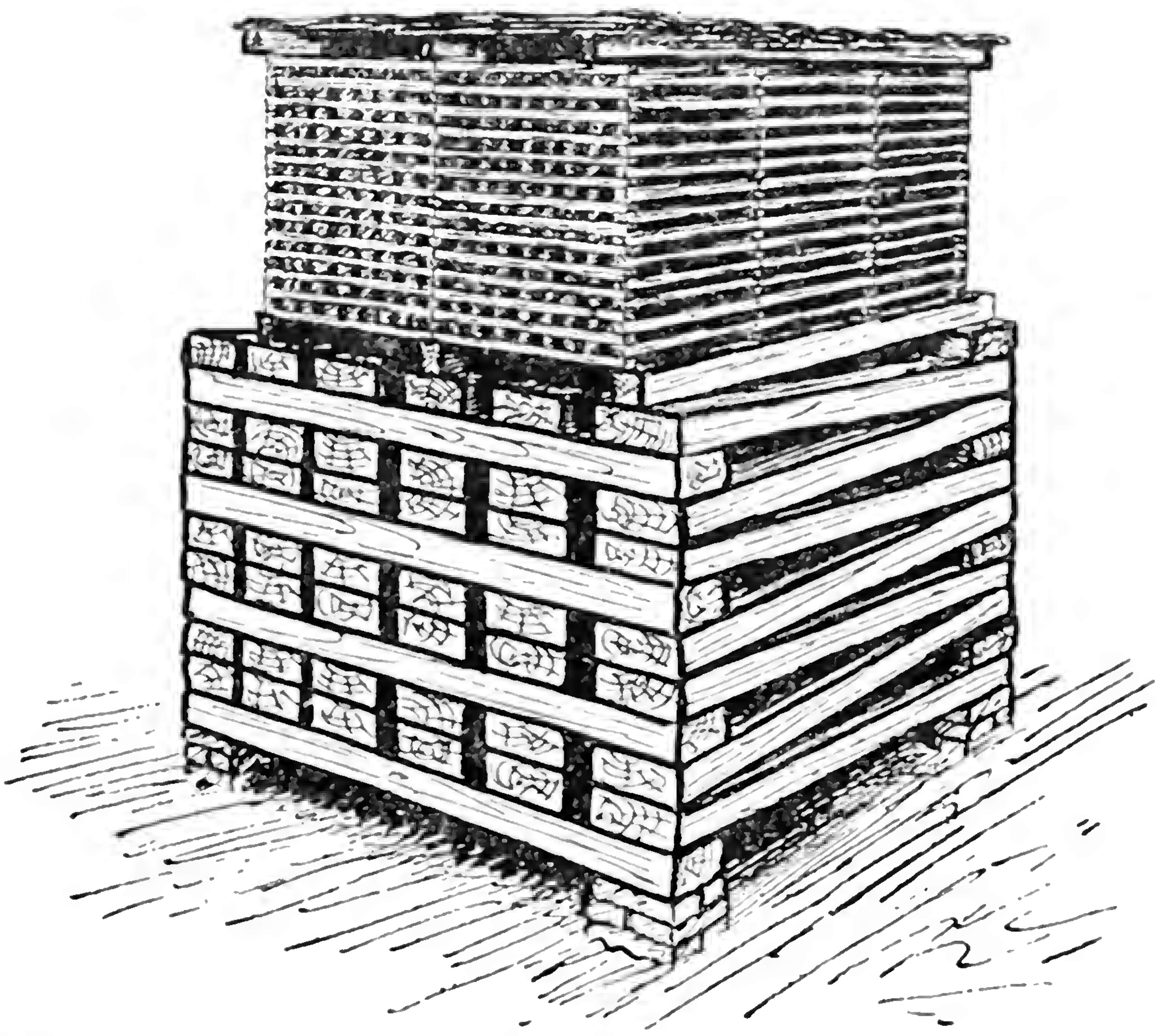


FIG. 9. Methods of piling sleepers or large scantlings (below) and small furniture squares (on top).

suitably spaced. It is always a good plan to put in a few piling sticks running the full width of the stack in order to give rigidity. Clearly this method is not conducive to a minimum of warping, but economic considerations make for its adoption.

So much for methods of stacking. We have now to consider how we can control the drying to suit the particular material in hand.

Nature is so often difficult in her reactions to timber seasoning that it is encouraging to be able to report one particular in which she is accommodating: It so happens that most of the species liable to split severely in drying are relatively resistant to serious forms of fungal attack, while those that are tolerant of rapid drying are often peculiarly susceptible to fungi which can seriously lower the value of the timber. Hardwoods like oak

and beech which split easily when exposed to drying winds can be left for some months under humid conditions without anything more serious occurring than superficial staining and the development of mould growths which can be brushed off the dry timber. Softwoods like red and white deal (Scots pine and common spruce) can be dried rapidly without splitting, but will stain badly in the sapwood in a few days if the weather is warm and damp and the surface of the timber wet.

Therefore, generally speaking, the best time to pile refractory hardwoods is in late autumn or early winter when some months of slow drying weather may be expected, and conversely, the best time to stack free-drying softwoods is in the spring or summer, when superficial drying at least will be accomplished in a short time. We shall see a little later how we can do something to get over the time of year and yet produce an approximation to the same drying conditions.

Many common hardwoods like oak, ash, beech and chestnut, to mention a few of the most important, dry slower than the ordinary softwoods like Scots pine, Norway spruce, Douglas fir and larch. This is sometimes partly because they contain more moisture initially, but mostly because the structure of the timber is more complicated and dense, rendering the withdrawal of moisture more difficult. Yet, with a few exceptions, the slow-drying hardwoods are those most resistant to staining fungi. If piled in the winter, drying proceeds slowly—as is desirable—during the cold weather and continues steadily throughout the summer months till autumn sets in again. By this time timber up to 2 inches thick should be fairly well air-seasoned and should be taken indoors. On the other hand, if hardwoods of this type are piled in the spring or summer, not only will they be very liable to split, owing to the fact that they experience relatively fast drying conditions while still very wet and weak, but also they will still be incompletely seasoned by autumn, and will therefore have to be left right through the winter, when practically no drying will take place since the timber is by this time tolerably dry, and well into the following summer before they have seasoned to the same point as the winter-stacked timber referred to above. In other words, whereas in the former case seasoning would be completed in under a year, in the latter at least eighteen months would be required.

In the case of the softwood group referred to above, spring or summer piling is desirable from the staining aspect, and as these timbers are relatively fast driers, with little tendency to split incidentally, sizes up to 2 inches thick will be fairly thoroughly air-dry by the autumn of the same year.

Success or failure in air-drying depends to a large extent on the weather. A hot dry spell occurring soon after a refractory timber like oak has been stacked for drying will cause extensive splitting of the surface and ends and exposed edges. A warm humid spell in spring or summer will cause freshly-stacked softwoods to stain badly. These are misfortunes which have to be borne just as the farmer has to put up with floods and droughts which ruin his crops.

While we are at the mercy of the weather in some ways, we can control it in others. We can accelerate drying to some extent by providing optimum ventilation, and we can keep it down by restricting the flow of air over the timber. This is done by employing different sizes of piling sticks.

Circumstances do not always permit of stacking refractory hardwoods in winter. So whereas one could use piling sticks 1 inch thick when piling oak or beech in winter, it would not be advisable to use sticks thicker than ½ inch in spring or summer. Unfortunately the use of thinner sticks means slower drying at all times, and not only just at the initial stage when it may be more or less obligatory.

Abnormally thick sticks, say 1½ inch, can be employed with softwoods piled in winter or early spring to accelerate drying of the surface and so minimize the risk of damage from staining fungi.

In America it is common practice to dip the timber, as it comes off the saw, in a preservative liquid designed to prevent sap-stain.

Surface treatment of this sort has only a temporary preservative effect, but it generally suffices to see the timber through the danger period.

As explained in the previous chapter, end-splitting or checking is a defect very likely to occur with practically any timber on account of the rapid drying, with consequent shrinkage, through the end-grain.

In air-drying a large proportion of the ends must perforce be exposed to the best air circulation, and therefore apart from other considerations drying will tend to be faster at this point. True, exposed ends are also the first parts to be wetted when rain falls, but absorption of moisture and consequent swelling will only close temporarily, and not mend, splits which have already developed.

Many methods of protecting the end-grain of timber during seasoning have been devised. These range from actually painting the ends to shading them with overhanging, that is projecting, piling sticks. The latter is a fairly cheap and tolerably effective way, the former is expensive but very effective if the right kind of coating is used. The best end-coating paint for air-seasoning purposes known to the author is one developed by The U.S. Forest Products Laboratory, Madison, Wisconsin, U.S.A., called Gloss Oil. The formula for making up Gloss Oil is as follows:

"The oil itself should be of a thick grade, made up (by the paint manufacturer) of about 8 parts quicklime, 100 parts rosin, and 57·5 parts spirit (naphtha). To 100 parts of the gloss oil add 25 parts barytes and 25 parts of asbestine (fibrous talc). One or two parts of lampblack may also be added if a black coating is desired."

Any paint manufacturer will make up this coating, but the prices charged vary considerably. Even at about 3*s*. per gallon—the cheapest quotation likely to be received—the paint is expensive as it has to be applied thick and carried round the edges to be effective. Only in the case of valuable timbers is the use of an end-coating paint of this nature likely to be justified on economic grounds.

Other end-protecting methods having some merits are canvas, plywood and metal cleats. Canvas can be spread over the entire end of a stack and taken down when drying has proceeded for some time. Sheets of scrap plywood can be tacked to the ends of timber stacked in log form.

Many trees are in a state of stress when felled, and when sawn into planks are liable to split from end to end. To obviate 'shaking off the saw' cleats are often nailed on to the ends. If this is done the use of metal cleats in preference to wooden ones is strongly advocated. It will be clear that as the timber dries it

will try to shrink, but a wooden cleat will restrain this and splitting will almost certainly result. A metal cleat will buckle, however. A metal cleat provides some measure of end-protection, but cannot compare with a good paint in this respect.

Gauging the Progress of Drying. Some general indications of the drying rates of different classes of timber have been made, but in a variable climate like ours a generalization of this sort means little.

The old air-seasoning rule of 'a year to the inch' may suit the type of man who does not need to watch his costing very closely and who cares to run the risk of using unseasoned timber. An oak board piled in winter will probably be well seasoned within a year, but a similar board piled towards the end of a wet summer may well be far from thoroughly air-seasoned in a year's time. A pine board 1 inch thick will certainly be well dried within a year irrespective of the time it is piled, but it may also be drier after a fortnight than in the eleven succeeding months.

While we could dispense with this crude rule and substitute many others concerning different species, piling times, thicknesses, &c., there would still be an element of waste and risk. There is a fairly simple way of cutting out all doubt and enabling the progress of drying to be known from month to month, week to week and even day to day if necessary.

This consists of using a sample board or plank built into the pile in such a way that it can easily be withdrawn, and weighing it at intervals. The sample used should be a piece typical of the stack as a whole. Space should be provided for it in the middle of the stack so that one end is flush with the end of the pile. The piling sticks which pass over the sample piece should be notched on their under side so that they bridge it to allow of its withdrawal. Before the sample is placed in position its moisture content should be determined in the manner described on page 6.

Supposing a plank 8 feet long is selected for the sample. It will be sufficient to leave a space in the pile 6 feet 6 inches long because we are going to take a moisture test from each end, and before doing so will discard about 9 inches to make sure we are getting away from end-drying effects. A moisture section the full width and thickness of the plank, but only about half an

inch in the direction of the grain, should then be cut from each end (after discarding 9 inches or so). These moisture sections are then weighed at once and placed in an oven to dry. The sample plank should next be weighed. Let us suppose it weighs 20 lb. When the moisture sections have been dried and weighed again we can compute their moisture contents in the manner described on page 8. Let us assume that one test gave a moisture-content value of 82 per cent., and the other section was found to have a moisture content of 90 per cent. We now make the assumption that the initial moisture content of the sample plank was 86 per cent., that is the average of the moisture content of the two sections cut from it.

Substituting these values in the formula:

$$\text{Moisture Content \%} = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Dry Weight}} \times 100$$

we get:

$$86 = \frac{20 - \text{Dry Weight}}{\text{Dry Weight}} \times 100$$

This can be simplified to :

$$\text{Dry Weight} = \frac{\text{Wet Weight}}{\left(\frac{\text{Moisture Content}}{100} + 1\right)} = \frac{20}{\left(\frac{86}{100} + 1\right)}$$

$$= 10\tfrac{3}{4} \text{ lb. approx.}$$

Having calculated the estimated dry weight of the sample in this fashion, it is a simple matter to compute the moisture content at any time later when the sample is weighed, or alternatively to find the weight to which the sample must fall before the stack can be considered seasoned.

For reasons which will be discussed later it is rarely possible to air-season to below about 20 per cent. moisture content in this country. Accepting this fact, we can calculate what the weight of the sample will be when it has dried to 20 per cent. moisture content:

$$20 = \frac{(\text{Weight at 20\% Moisture Content}) - 10\tfrac{3}{4}}{10\tfrac{3}{4}} \times 100$$

$$\frac{20}{100} = \frac{\text{Weight}}{10\tfrac{3}{4}} - 1$$

or Weight required

$$=\left(\frac{20}{100}+1\right)\times 10\tfrac{3}{4} = 12{\cdot}9 \text{ or nearly 13 lb.}$$

It is, however, a better plan to weigh the sample periodically and calculate the current moisture content. If this is done it can be seen how drying is progressing, and decide accordingly. Thus supposing the moisture content was found to have fallen to, say, 22 per cent. in October, there would be little point in leaving the stack standing over the winter when practically no drying would take place, and the timber might even become wetter.

Drying Times. Having now guarded the reader against too blind a belief in generalization and having advised him how to check his own drying rates, we can state in general terms some very approximate drying times. These are given more as a rough guide to assist in planning air-seasoning operations than for any other reason. Softwoods 1 inch thick, if piled in spring, should dry to about 20 per cent. moisture content in 2 to 3 months; 2 inch thick softwoods will require 3 to 4 months under similar conditions. Hardwoods 1 inch thick, if piled in the autumn, should dry to about 20 per cent. by the following summer, whereas under favourable conditions, 2 inch hardwoods should dry to about the same figure in a year if piled in October or November.

Certain species of timber need special treatment if the best results are to be obtained, and so the following notes on various common English timbers are appended:

Ash (*Fraxinus excelsior*). Ash should never be left in the log for any length of time or it will discolour badly. It air-seasons well and fairly rapidly, but shakes will be much inclined to open and extend. Sawing along the worst shakes is advisable.

Beech (*Fagus sylvatica*). Beech should also be converted soon after felling or it will become brown and 'doty'. It is rather inclined to split, so should preferably be piled in winter. It air-seasons fairly well and quite fast.

Sweet Chestnut (*Castanea sativa*). This timber air-seasons slowly and wet patches are liable to be retained even for long

periods. On the other hand, it is not prone to splitting and checking and so can be piled even if the weather is fairly warm and dry.

The Elms: English or **common** (*Ulmus procera*), **Dutch Elm** (*Ulmus hollandica*), **Wych Elm** (*Ulmus glabra*). Elm air-seasons rapidly with little tendency to split, but is very liable to warp on account of the twisted grain. In order to reduce warping as much as possible, piling sticks should be spaced at frequent intervals, particularly with thin material, and special care should be taken to see that the stack is well constructed with sticks in good vertical alignment, &c.

Oak (*Quercus spp.*). Oak air-dries slowly with a pronounced tendency to split and check. It should therefore be piled in the late autumn or early winter. Some protection of the end-grain is advisable in order to reduce end-splits. Provided the ends of logs are protected and the bark is left on, oak can be left in that form for a long period, although the sapwood will probably decay. Freshly-sawn oak should never be left lying about in the sun even for an hour or two or it will develop fine splits all over.

Sycamore (*Acer pseudoplatanus*). Sycamore air-seasons well, but special care is needed to prevent the timber staining. The only simple way of preventing staining is to dry off the surface as rapidly as possible. Probably the best way of doing this is to pile the sawn timber on edge and on end against a wall or some other support, leaving a good air-space between each piece. After a few days of dry weather the timber can be piled in the ordinary way, 1 inch thick piling sticks being used.

Douglas Fir (*Pseudotsuga douglasii*). Douglas fir air-seasons rapidly and well, with some tendency to split and for knots to loosen.

Larch (*Larix decidua*). Larch air-seasons rapidly with some tendency to split and warp. It should therefore be piled carefully.

Corsican Pine (*Pinus nigra*). Corsican pine air-seasons rapidly and well, but is very much inclined to stain. Because of this, every effort should be made to secure rapid drying of the surface. Winter piling is therefore not advisable, unless the weather

is likely to remain cold for some time. Fairly thick piling sticks (at least 1 inch) should be used, and ample ventilation secured in every possible way.

Scots Pine (*Pinus sylvestris*). The remarks referring to Corsican pine above apply also to Scots pine in all respects.

Norway Spruce (*Picea abies*). Spruce air-seasons fairly fast, but has some tendency to warp, split and stain, and knots are inclined to split and loosen. This is the type of timber that presents difficulties, because if winter stacked it will probably stain, and if summer stacked it will split and check. The best compromise is to pile during a cold dry spell in winter or spring.

There is one very serious limitation to air-seasoning which cannot be too highly emphasized: In this country it is quite impossible to dry timber sufficiently, in the open air or in an unheated store, for use indoors where artificial heat will be applied. Clearly the degree to which timber can be air-seasoned depends on the condition of the atmosphere—and not on the condition prevailing for a few days, but the average over a period of weeks. Even in the height of summer the average humidity of the outdoor air is considerably in excess of that found in a heated building in winter. As we shall see later, timber for indoor use should be dried to a moisture content of about 12 per cent. Timber stacked out of doors usually comes into equilibrium with the atmosphere at a moisture content of about 20 per cent. Under exceptionally dry conditions (during a heat wave, for instance), thin boards may dry down to about 14 per cent. moisture content, but the usual range is between 17 and 23 per cent., depending on the time of year.

Therefore, if air-seasoned timber is taken straight from the stack, manufactured and placed indoors, *drying and shrinkage are inevitable*. These may be accompanied by warping and splitting.

Obviously air-seasoned timber is perfectly satisfactory for outdoor use or for positions where no heating is in operation. It can, of course, be used indoors, provided shrinkage is of no serious consequence, and is, in fact, universally used for carcassing work in building—but not always without consequences which the occupant, if not the builder, might consider serious.

CHAPTER IV

THE KILN-SEASONING OF TIMBER

HOW KILN-DRYING WORKS—TYPES OF TIMBER-DRYING KILNS: THE PROGRESSIVE KILN, THE COMPARTMENT KILN, NATURAL DRAUGHT KILNS, FORCED DRAUGHT KILNS—KILN CONTROL—WARMING UP A KILN—WHEN IS TIMBER DRY?—SECURING UNIFORMLY DRIED TIMBER—KILN-DRYING SCHEDULES—STREAMING TO KILL MOULD GROWTHS—DRYING TIMES—KILN APPARATUS AND INSTRUMENTS KILN OPERATION.

It may have been remarked that whereas the last chapter was headed 'The Air-*Drying* of Timber', this one is entitled 'The Kiln-*Seasoning* of Timber'. This has been done deliberately in order to emphasize again that in the writer's opinion, as far as timber is concerned, 'Drying' and 'Seasoning' are synonymous. Many people will refer to 'natural seasoning' and 'artificial drying'. If they imply a distinction they are basing it on prejudice and tradition, but not on fact.

Let it be clearly understood that the two methods are essentally the same. They both rely on the circulation of air over the surfaces of the timber to evaporate and remove moisture. When we say this we are referring to the only present practicable method of artificial drying known as kiln-seasoning. Other methods, not necessarily involving the use of air, at present in the experimental stage, are referred to in a later chapter.

There may be said to be two essential differences between air-seasoning and kiln-seasoning: Kiln-seasoning implies controlled air conditions and air circulation, and the use of artificial heat.

The temperatures at present used in kiln-seasoning range from summer heat (90° to 100° F.) to the boiling-point of water (212° F.). Temperatures in excess of 212° F. have not so far proved successful.

Kiln-seasoning generally produces faster drying than air-seasoning for two reasons:

(1) Because the circulation of air over the surfaces of the timber is, on the average, considerably more rapid and positive.

(2) Because the use of higher temperatures causes the moisture within the timber to move more rapidly to the surfaces from which it can be evaporated.

Let no one suppose that the rate of evaporation of moisture is always higher in kiln-seasoning than in air-seasoning. Very often it is lower. Better use is, however, made of the circulating air. Towards the latter stages of air-drying most of the air passing over the timber moves on with hardly any added moisture, but in kiln-seasoning because of the more generous supply of moisture from the centre to the surface, the circulating air always leaves a stack of timber at a higher humidity than when it entered.

Air at any given temperature will hold a certain weight of moisture per unit of volume. If it is heated, the same volume of air will hold a greater weight of moisture. Consequently, if air is raised in temperature it will become drier if no moisture is added. Ordinary atmospheric air, even if saturated (100 per cent. humidity), having a temperature of, say, 50° F. when heated to quite a moderate kiln-drying temperature (say 130° F.), will be dried to a humidity of less than 10 per cent. Drier, that is, than any air ever found outdoors or indoors in this country, except perhaps in isolated spots momentarily. If air as dry as this were introduced to a stack of fairly wet timber the rate of evaporation would be so great that the results would be disastrous.

It therefore follows that if we are to use hot air for drying timber we must add moisture to raise the humidity and so keep the rate of evaporation within safe limits.

If a certain volume of hot and very dry air was introduced to a pile of wet timber and kept stationary, probably no damage would occur, because the air would soon become saturated and evaporation would cease. It would also become cooled, because the process of evaporation requires the expenditure of heat energy which would be drawn from the air. When cooled it would be able to hold much less moisture.

But in a timber-drying kiln the air is never stationary, it is always being moved along, so that it rarely has a chance to become saturated unless the timber is very wet superficially. Moisture will, however, be added. In some cases the amount added will be sufficient to keep the evaporation within safe

limits, and certain green softwoods—which dry freely and are relatively tolerant of severe conditions—are, in fact, successfully dried without any artificial moistening of the air.

Again, if the rate of circulation is restricted, sufficient moistening of the air in relation to the rate of supply of moisture to the surfaces of the timber will be secured.

But in far the majority of cases of drying, and in nearly all designs of kiln, some provision is made for moistening or humidifying the circulating air.

A kiln, then, may be roughly described as a chamber for containing wood to be dried, provided with means for circulating air through the timber. Some means being also provided for heating the air, and generally also for humidifying it.

Obviously the same air cannot be continually re-circulated through the timber, or it would soon become saturated or attain a humidity in equilibrium with the moisture content of the wood.

Various ways of getting over this objection are employed:

(1) All the air is exhausted from the kiln after passing through the timber and fresh air is taken in, heated and humidified.

(2) The air as it comes from the timber stack is cooled so that moisture is condensed and drained away. It is then reheated, re-humidified, if required, and re-circulated.

(3) A certain amount of exhaust air is allowed to escape and an equal amount of fresh air is introduced. The fresh air being at, or near, atmospheric temperature becomes very dry air when heated up to the kiln temperature, and so has the effect of drying the large bulk of air in the kiln.

Method (1) is very wasteful of heat, though it is still used. Method (2) requires some means of artificially cooling the air. Method (3) is almost universally adopted nowadays.

It should be remembered that the kiln walls, floor and roof will act as condensers to a certain extent and moisture can be partially removed in this way.

Having seen something of how kiln-drying is effected and the rough essentials of a kiln, let us consider the various types of drying kilns available and in practical use to-day. Some designs of kiln which, although excellent in their time, have now become obsolete for one reason or another, are not included.

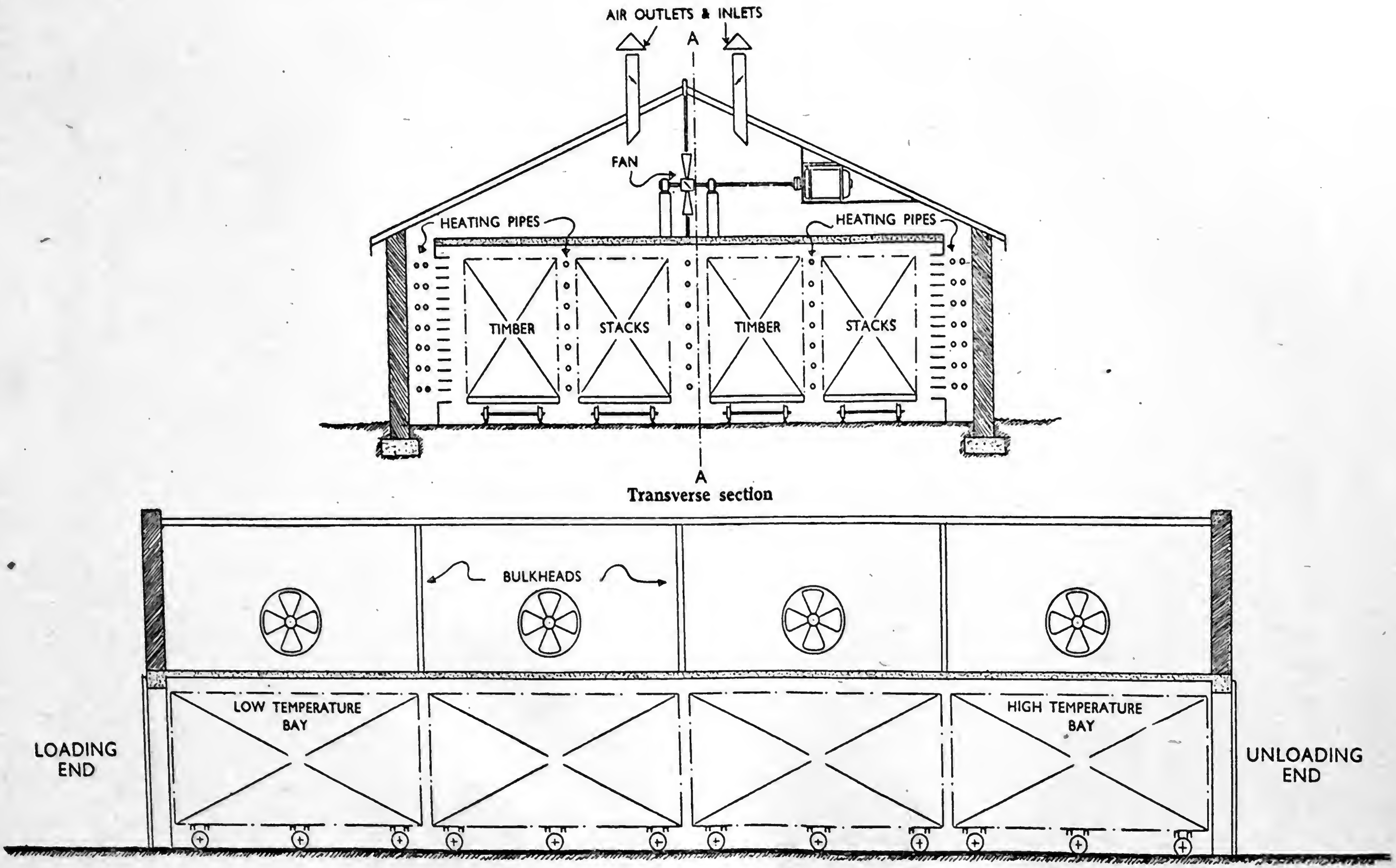
Types of Timber-Drying Kilns

A Progressive Kiln (an example of which is shown diagrammatically in Fig. 10) is one in which the timber travels progressively from one end to the other, becoming drier as it moves along. At one time the progressive kiln was used extensively for drying timber of all sorts, but now its use is practically confined (in this country at any rate) to such thin sizes as veneers, box shooks, and the like. There are still many old progressive kilns giving tolerably good service in drying boards, planks and scantlings, but as far as the author is aware, no progressive kiln has been installed in this country for this purpose for the last ten years at least. On the Continent of Europe, however, particularly in Scandinavia, modern progressive kilns of the type shown in the figure are being used extensively for drying off softwoods.

By 'drying off' is meant removing the free moisture so that the timber becomes light enough for easy handling and shipping and is not so liable to staining.

In the author's opinion the progressive kiln is not particularly suited to operations in this country (except for the thin sizes referred to), so we will confine ourselves here to a few brief remarks.

In the design shown, which represents a considerable advance on the type usually found here, the kiln length is divided into zones. At the loading end of the kiln the temperature is relatively low and the air fairly humid. After a short time in this first zone the timber is moved on to the next, where the temperature is maintained at a slightly higher level and the humidity of the air is lower. And so the timber advances from zone to zone till it is at the unloading end, where the air is hottest and driest. It is then sufficiently dry and can be withdrawn. Each zone is provided with its own fan for circulating the air, its own battery of steam-heated coils for heating the air, and sometimes with individual steam-jets for humidifying the air. The air is circulated across the kiln, descending down one side, passing through heating pipes, a truck-load of timber, another battery of hot pipes, another truck, and so on, till it reaches the other side. It then ascends and returns to the fan. Fresh air is introduced and spent air exhausted at the points shown as required.



Longitudinal section on AA.

FIG. 10. Progressive kiln. Forced-draught—modern type.

Very often no fans are used in progressive kilns and air circulation is effected on natural-draught principles. Natural circulation is described below under Natural-Draught Kilns.

When used for drying veneers, box parts and articles of that nature, an endless band is built into a progressive kiln and the timber moves continually.

By far the most suitable type of kiln for the average timber operator in this country is the **Compartment Kiln.** Here the timber is held stationary and the air is gradually heated up and dried as the moisture content of the timber falls. The compartment kiln is found in two types: (*a*) as a natural-draught kiln, or (*b*) as a forced-draught kiln. Many designs of each type are available and it is proposed to describe the most usual and useful.

The **Natural-Draught** or Natural-Circulation Kiln is shown in its simplest form in Fig. 11. Air is heated in the basement (usually by steam-heated pipes), is humidified by steam or water-jets (usually steam), and rises (because heating the air makes it lighter—' Hot air rises'). It comes up between the two stacks of timber, which are stacked in much the same way that timber is stacked for air-seasoning. As it is unable to escape at the top (and because it is being sucked from the other side) it enters between the rows of timber and travels across to the two sides of the kiln chamber. In its passage through the timber it evaporates moisture and so becomes cooled and humidified. Consequently, on coming out into the space between the pile and the wall it falls. On its return journey to the basement it passes some holes cut in the walls communicating with chimneys. If these holes are uncovered, some air escapes. The remainder returns to the vicinity of the heating pipes and here fresh air can be admitted to make up the balance that has escaped.

It is advantageous if the floor of the kiln is provided with a slight fall to one side. A gutter running down this side can communicate with a drain. This is all for the purpose of draining away any moisture condensing within the kiln chamber,or in the chimneys.

It will be clear that the rate of air circulation in a kiln of this type is dependent on the difference in temperature between the centre of the kiln and the outsides, the draught effect produced

by the chimneys, the resistance offered by the comparatively rough surface of the timber, the slight ejector effect from the humidifying jets, and so on.

The best compromise is obtained when the cross-sectional dimensions of the kiln are as shown in the figure, but even so the rate of circulation is very slow—of the order of ½ to 1 foot per

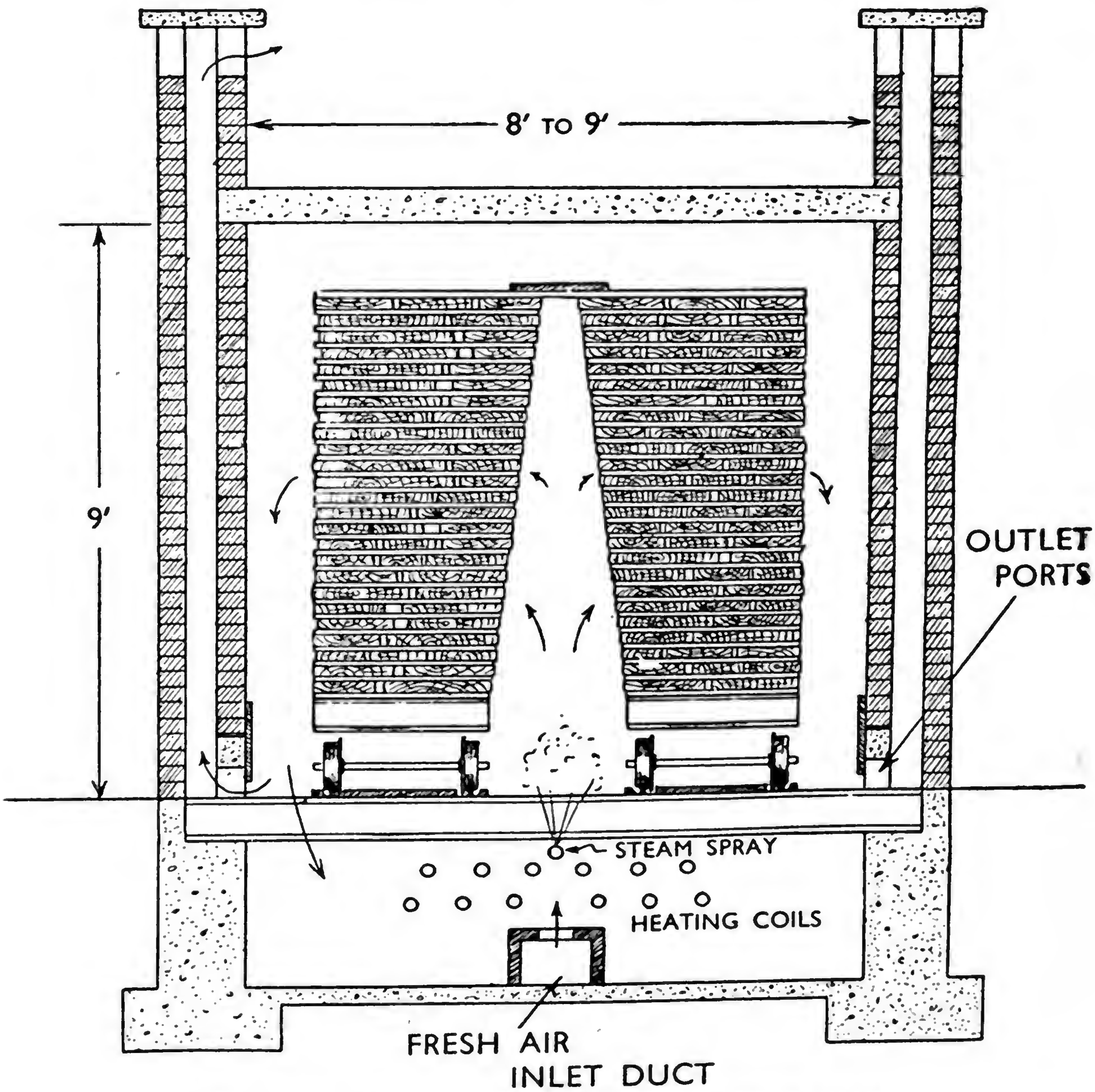


FIG. 11. Natural-draught kiln (simple type).

second. Even comparatively slight imperfections in the construction of the stack can upset the circulation considerably. External conditions such as wind and temperature can be troublesome. Heavy evaporation from very wet timber can cause damp patches of air to accumulate towards the air-outlet sides of the stacks, which the circulation is powerless to move.

It is not surprising, therefore, that many attempts have been made to improve matters. The great attraction of the natural draught kiln in the form just described is its simplicity. Such improvements as have been made have unfortunately necessitated complications, but it has been found possible to improve the air-circulation considerably and still retain the natural draught principle. Even the more complicated designs described below at least have no moving parts.

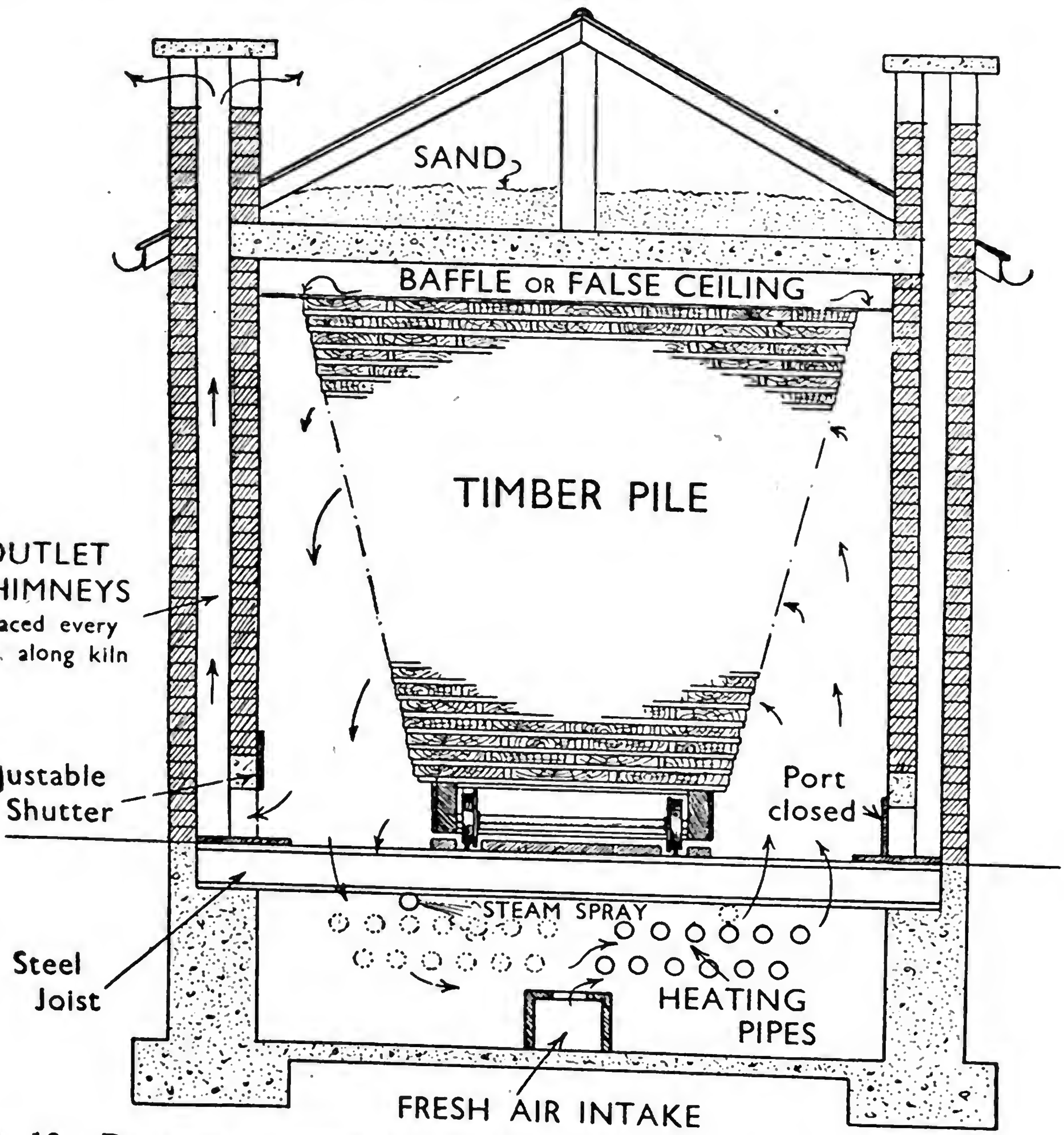
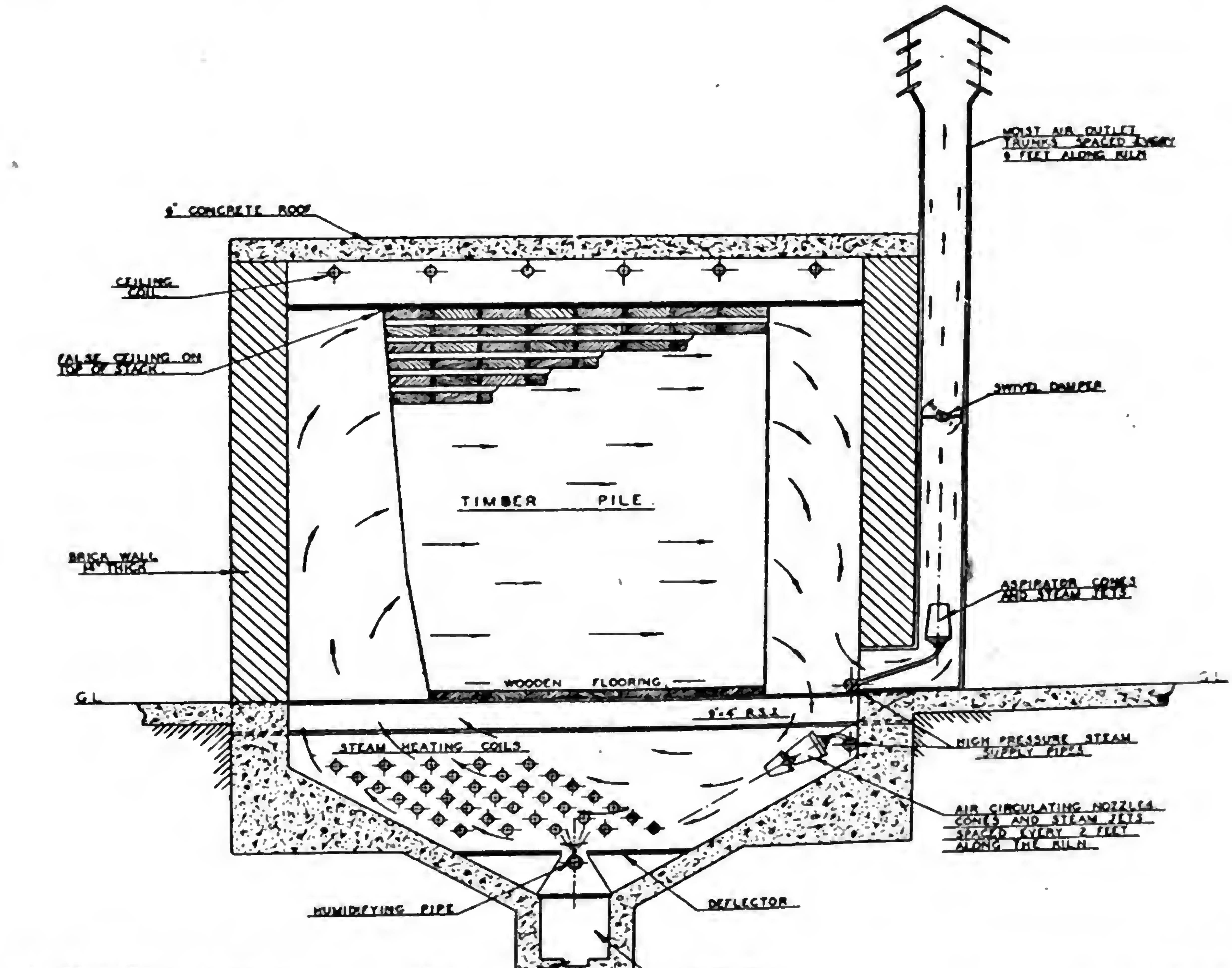


FIG. 12. Reversible natural-draught kiln (shown with air circulation from right to left through stack).

The **Natural-Draught Kiln** with **Reversible Circulation** shown in Fig. 12 owes its advantage over the simple type to the fact that it is possible to introduce relatively hot, dry air to just

those points most likely to accumulate damp, heavy air. This is effected simply by reversing the direction of the circulating air. Then what was the air-outlet side of the stack becomes the air-inlet side, and vice versa.

The reversing process is made possible by duplicating the heating systems, the humidifying systems and the air-exhaust systems. Supposing a circulation from right to left through the timber pile is required; then steam is admitted to the heating



(Courtesy of G. F. Wells

FIG. 13. Steam-jet kiln.

pipes on the right-hand side, the spray-pipe on the left-hand side which has holes drilled in it directed towards the right side of the kiln is turned on, and the ports communicating with the chimneys on the right-hand side are closed, while those on the left-hand side are opened. Air enters bearing to the right, passes through the hot pipes and rises up the right-hand side, while the steam-jets blow from left to right. The air passes through the stack and descends, some escapes through the chimneys on the left-hand side and the rest returns to the basement. Similarly,

by turning off the steam from the heating pipes on the right and admitting it to those on the left, by turning off the left-hand spray-pipe and turning on the right-hand one, and by closing the exhaust ports on the left and opening those on the right, the air can be caused to circulate from left to right, that is, the direction of circulation can be reversed.

When comparatively wet timber is being dried, the reversible type of kiln shows a decided saving in drying time over the simple type; even with timber partially seasoned prior to kilning a saving is effected.

The so-called **Steam-Jet Kiln.** The steam-jet kiln (Fig. 13) is really just the simple type of natural-draught kiln with the addition of a device for speeding up the circulation of the air. The device consists of an attachment to the steam-spray system. The ordinary method of humidifying the air in a kiln is to run a length of steam-pipe along the kiln providing small holes (about $\frac{1}{8}$ inch diameter) at intervals through which the steam is discharged into the air. In the steam-jet kiln these holes are replaced by special nozzles which are surrounded by metal truncated cones open at both ends. As steam is discharged through the nozzle air is drawn through the cones. By this means increased circulation and faster drying is possible. Aspirators of this type can be fitted into the chimneys too if desired, but obviously if this is done the consumption of heat is increased both because steam is blown up the chimneys and also because a larger proportion of air is exhausted and taken in.

Special Types of Natural-Draught Kilns

A variety of special applications of the natural-draught principle of air circulation as applied to timber-drying kilns have been developed from time to time. In one design heating is effected by passing the hot gases from a small furnace through a series of flues running in the base of the kiln. Fresh air is admitted at the bottom of the kiln and is exhausted by chimneys. No humidification is employed, but the circulation is restricted sufficiently for the moisture drawn from the timber to humidify the air to a safe point. This type of design appeals because it is self-contained, but it cannot dry as rapidly as the ordinary type because of the restricted ventilation required.

Again, in some designs the furnace gases themselves are circulated through the timber. Obviously the timber becomes superficially blackened by smoke, and the fire hazard has to be considered. Nevertheless, kilns of this type are used with tolerable success. They are not likely to make a large appeal in this country, however. In yet another type gas-jets are used to heat and humidify the air.

Forced-Draught Kilns. Forced-draught kilns, in which the air circulation is produced by mechanical means, are a fairly recent development. They are being installed in increasing numbers, however, and represent a considerable advance on the natural-draught system.

Many types of forced-draught compartment kilns have been designed but they can be divided into two categories:

(1) Those in which the air-circulating mechanism is outside the kiln chamber, known as **External-Fan Kilns,** and

(2) Those in which the entire circulating apparatus is within the kiln chamber known as **Internal-Fan Kilns.**

Chiefly because of the greater rate of circulation possible when fans are employed, forced-draught kilns dry timber more rapidly than natural-draught kilns. It has been found by experiment that the optimum air-speed past the surfaces of timber is of the order of 2 feet per second.* A properly designed fan kiln can secure this, but even the best type of natural-draught kiln will not have an air circulation of more than 1 foot per second.

The superiority of the forced-draught kiln over the natural-draught type is most marked when the timber being dried is very wet or parts with its moisture freely. Under such conditions a good natural-draught kiln may take half as long again as an efficient forced-draught kiln. The difference in drying times between the two types is less marked when the timber has been previously air-dried and when it is a slow-drying species like chestnut or oak.

As in the case of a natural-draught kiln, a fan kiln will not be efficient unless the air circulation extends to all parts of the timber pile and is reasonably uniform in velocity. Nothing is

* Higher speeds may be desirable for very wet free drying timber, but are not generally justified.

more irritating or more expensive than to withdraw a pile of timber from a kiln only to find that one part of the pile is still relatively wet.

Later we shall discuss methods of testing the air circulation to ensure that all parts of the timber stack are receiving an ample supply of air, and means of trying to rectify matters if they are not.

External-Fan Kilns. Many varieties of external-fan kiln are available, but in practically all types a centrifugal fan is arranged to draw air through a radiator and blow it along a duct

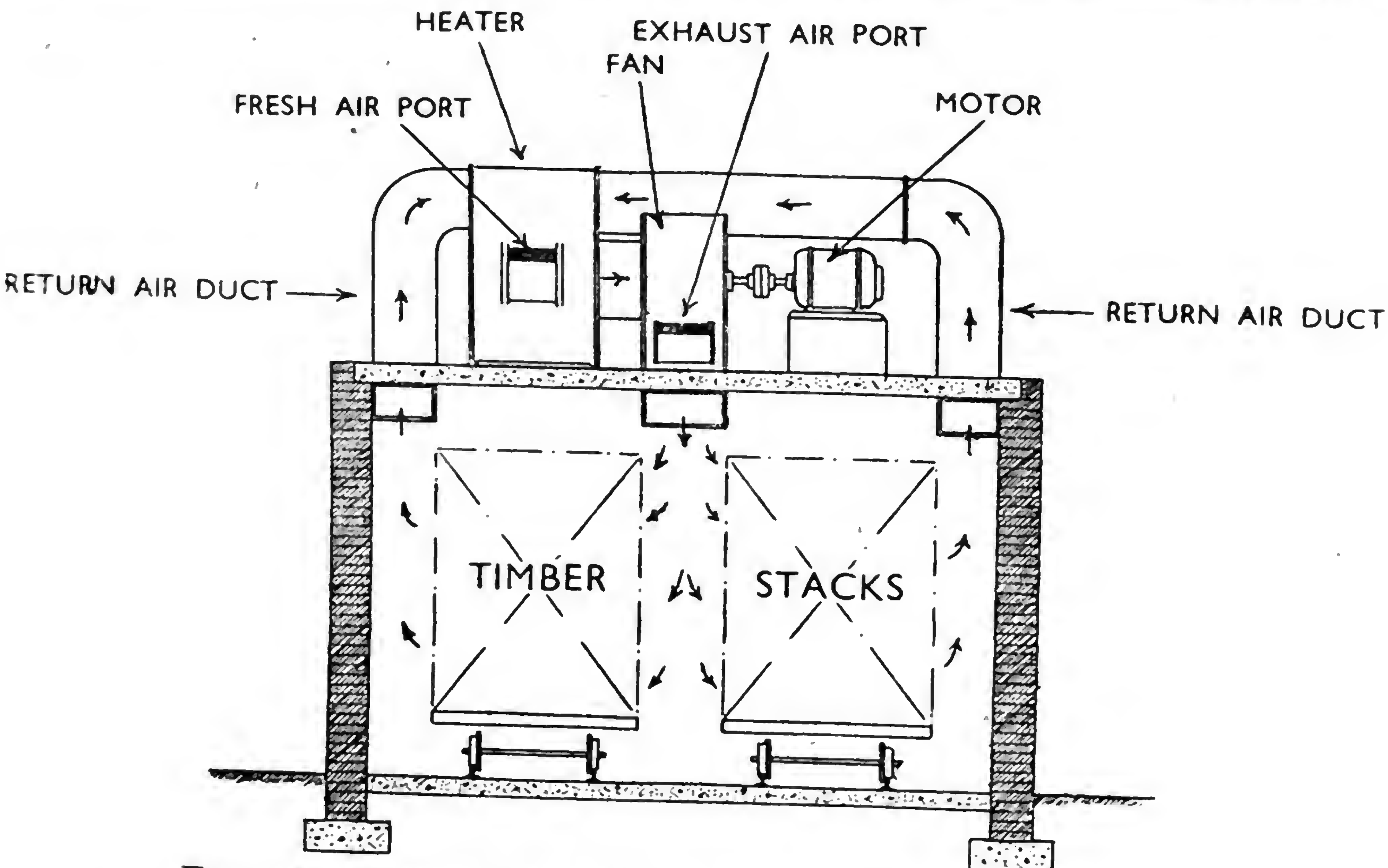
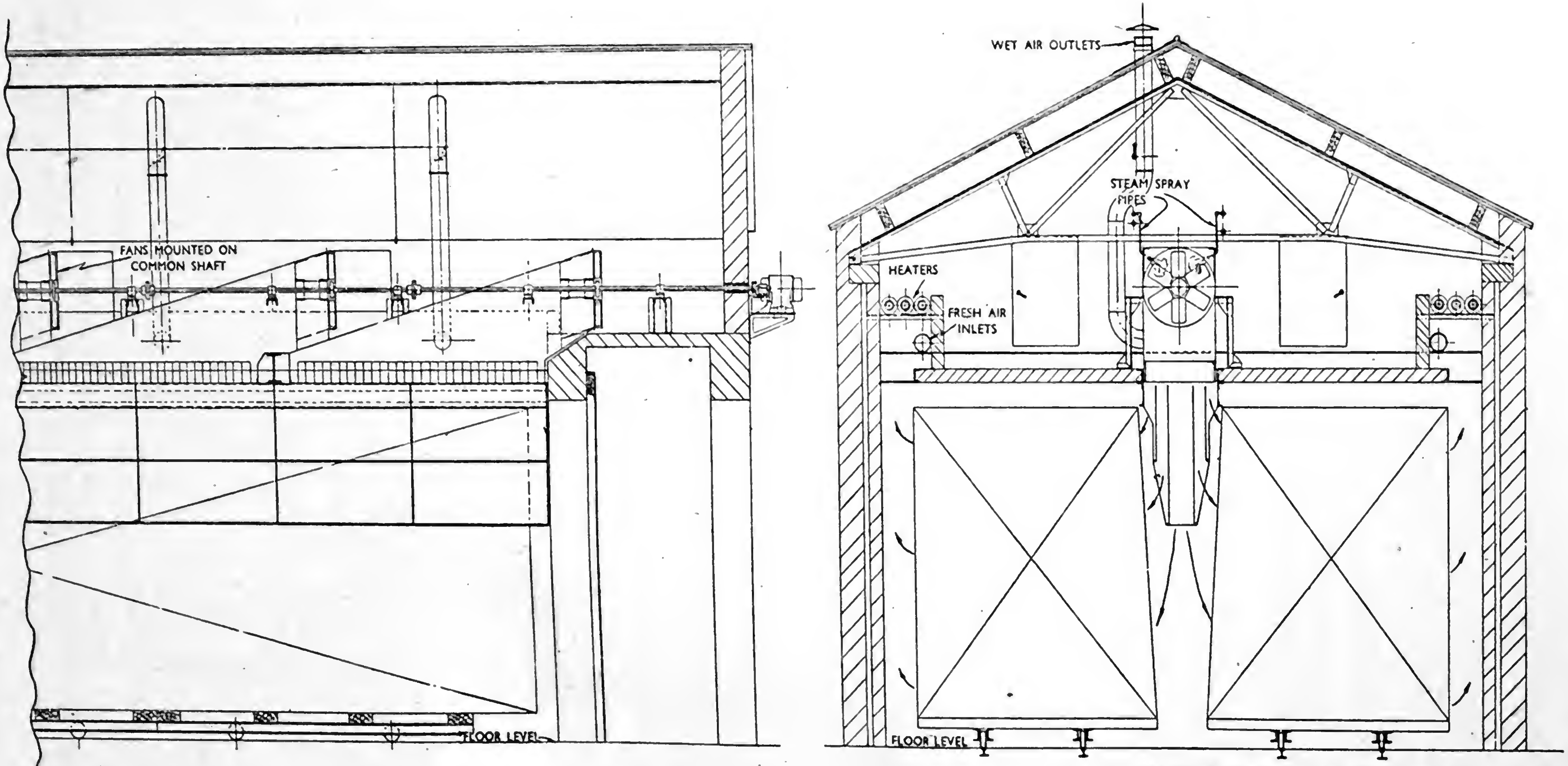


FIG. 14. External fan kiln. Double stack overhead type.

leading into the kiln-chamber. In the better designs the air is returned to the heater and fan after passing through the timber. The heating pipes and the humidifying system are sometimes located within the kiln. The fan can be situated in any convenient position and can blow air into the kiln from the bottom, the top or the side. In the kiln shown in the figure (Fig. 14) the fan and heater are on the roof, and air is blown into the duct running along the centre of the ceiling.

The duct delivers the air downwards between the two stacks of timber. After passing through the timber the air returns upwards to the two exhaust ducts and they conduct it back to the



Part longitudinal section

(Courtesy of The Thermal Engineering Co. Ltd.

Cross-section

FIG. 15. Overhead internal-fan kiln. Double-stack—longitudinal fan shaft.

heater and fan. The air is humidified by steam-jets in the heater casing, and air is taken in and exhausted at the points shown.

The Internal-Fan Kiln. Owing to the difficulty of securing uniform delivery of air from a long duct necessitated in the external-fan kiln, the internal-fan kiln was developed. As the name implies, the fans are inside the kiln-chamber, and instead of the usual single centrifugal fan found in the external-fan type of kiln there are generally several propeller fans.

The fans are located above or below the timber and can either be on a common shaft running longitudinally as in Fig. 15 or on each its own shaft, in which case they run across the kiln.

The kiln shown is called an overhead internal-fan kiln and the air is delivered downwards between two stacks of timber. It is heated by the steam-pipes on either side of the 'attic'. Steam-jets blow into the fans. The air passes through the fans, is deflected downwards by the sloping baffles, is further turned in direction by the grating, and so enters the space between the timber piles vertically.

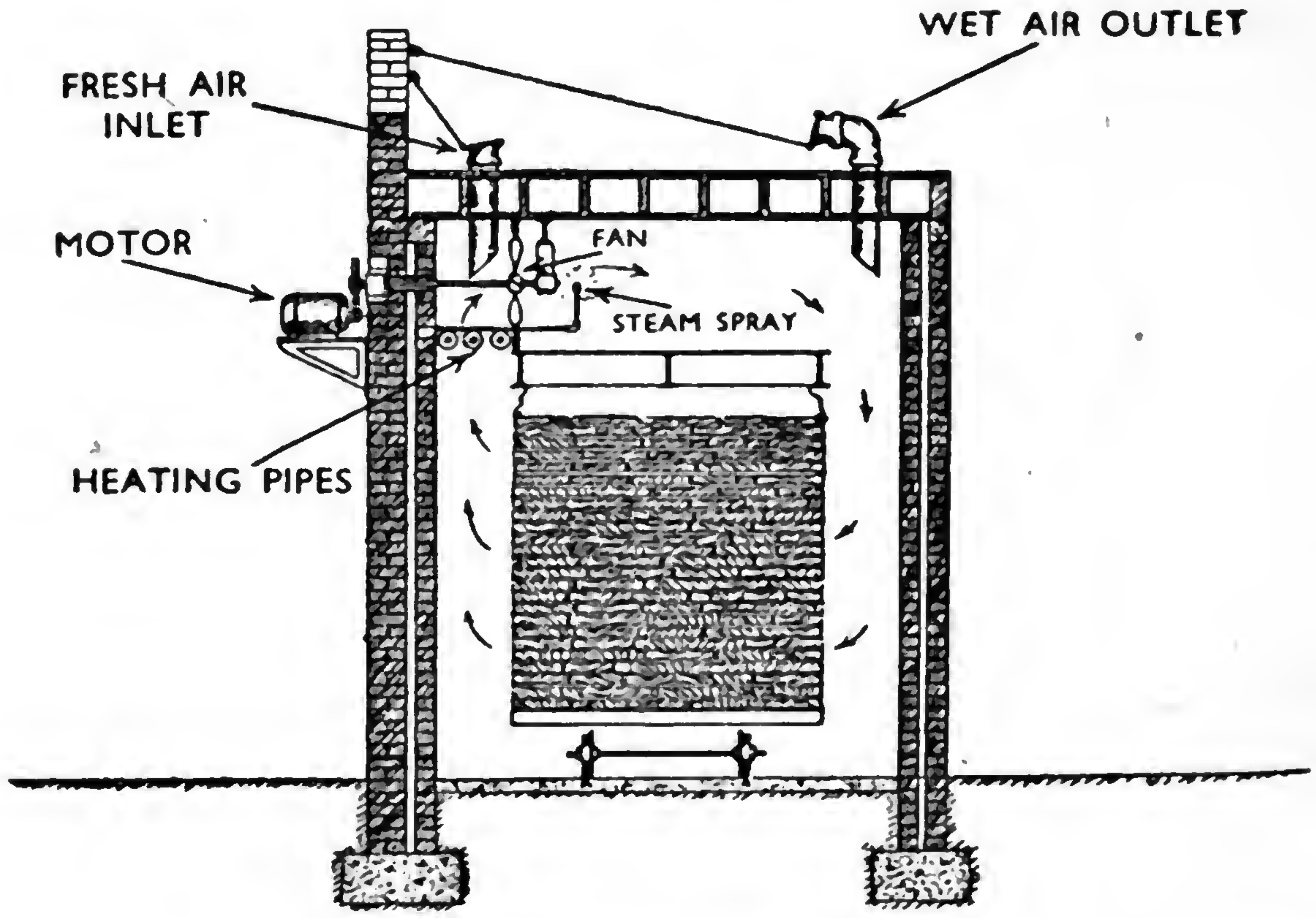
After passing through the timber it returns to the top of the kiln where it is re-heated, re-humidified and re-circulated. Fresh air is taken in and spent air exhausted at the points shown. A feature of this design is the provision of radial blades in front of each fan. These serve to take the swirl out of the air, so that eddies are reduced and a more streamlined path adopted.

The great advantage of the internal-fan kiln is the provision of circulating media at several points within the kiln. It is therefore much easier to secure a uniform delivery of air to all parts of the timber stack. Moreover, no heat and friction losses occur external to the kiln-chamber. Figs. 16 and 17 show other types of overhead-fan kilns.

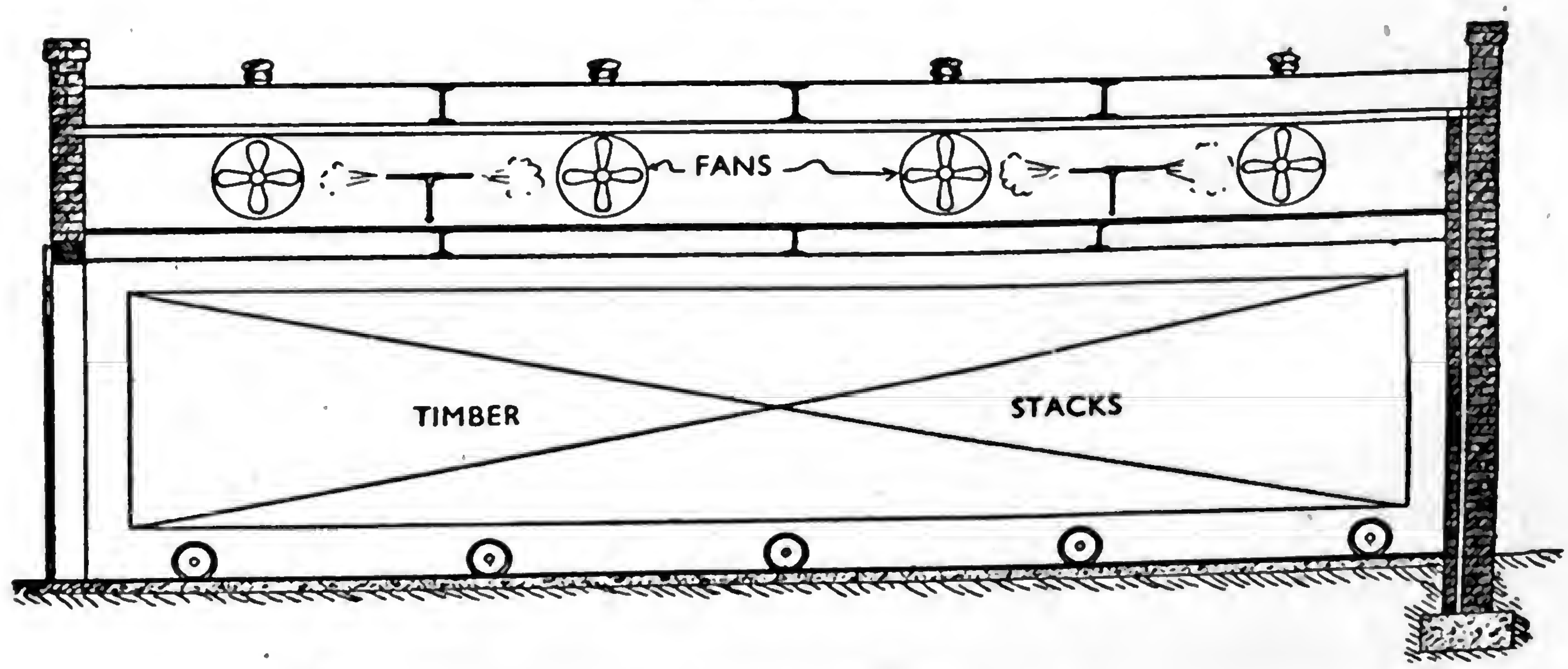
Kiln Control. As has been indicated earlier, kiln-drying is effected by passing hot, moist air through the timber. The particular temperature and humidity appropriate to any timber at any moisture content are all-important if efficient drying is to be secured. So-called **Drying Schedules** have been drawn up for practically all common timbers, and the only reliable way of applying these is to know the moisture content of the timber within the kiln at all times. This is easily known if sample pieces are built into the stack in the manner described on page 31.

The exact number of samples which it is desirable to employ will depend very much on the knowledge one has of the kiln's behaviour.

If the air circulation is known to be good and uniform it will probably suffice to have one sample on the air-inlet side of the stack and one on the air-outlet side. It is important, however,



Cross-section



Longitudinal section

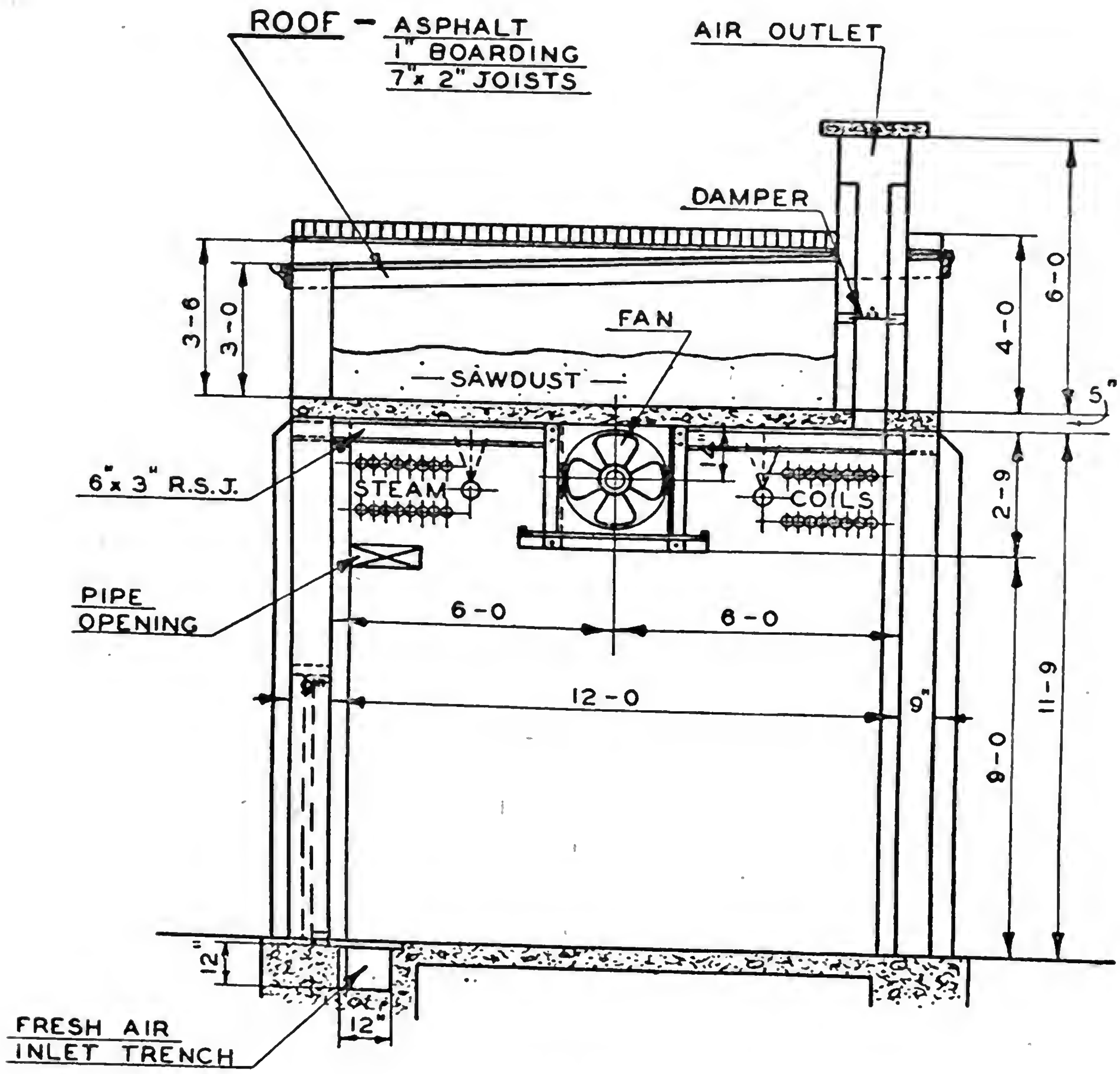
(Courtesy of The Thermal Engineering Co. Ltd.

FIG. 16. Cross-shaft overhead internal-fan kiln.

to be sure that the pieces selected for samples are typical of the load as a whole. If particularly dry pieces were used the load might suffer severely, since conditions appropriate to the moisture content of the samples might prove much too severe for wetter timber. Of course, if more than one sort of timber, or

more than one thickness, are included in a pile it is essential to have samples for each species and thickness. The kiln will then have to be controlled on the behaviour of the wettest sample (on the air-inlet side) of the thickest and most refractory species.

Assuming that typical samples have been selected and tested for moisture content, a drying schedule of the type given later can be applied with safety.

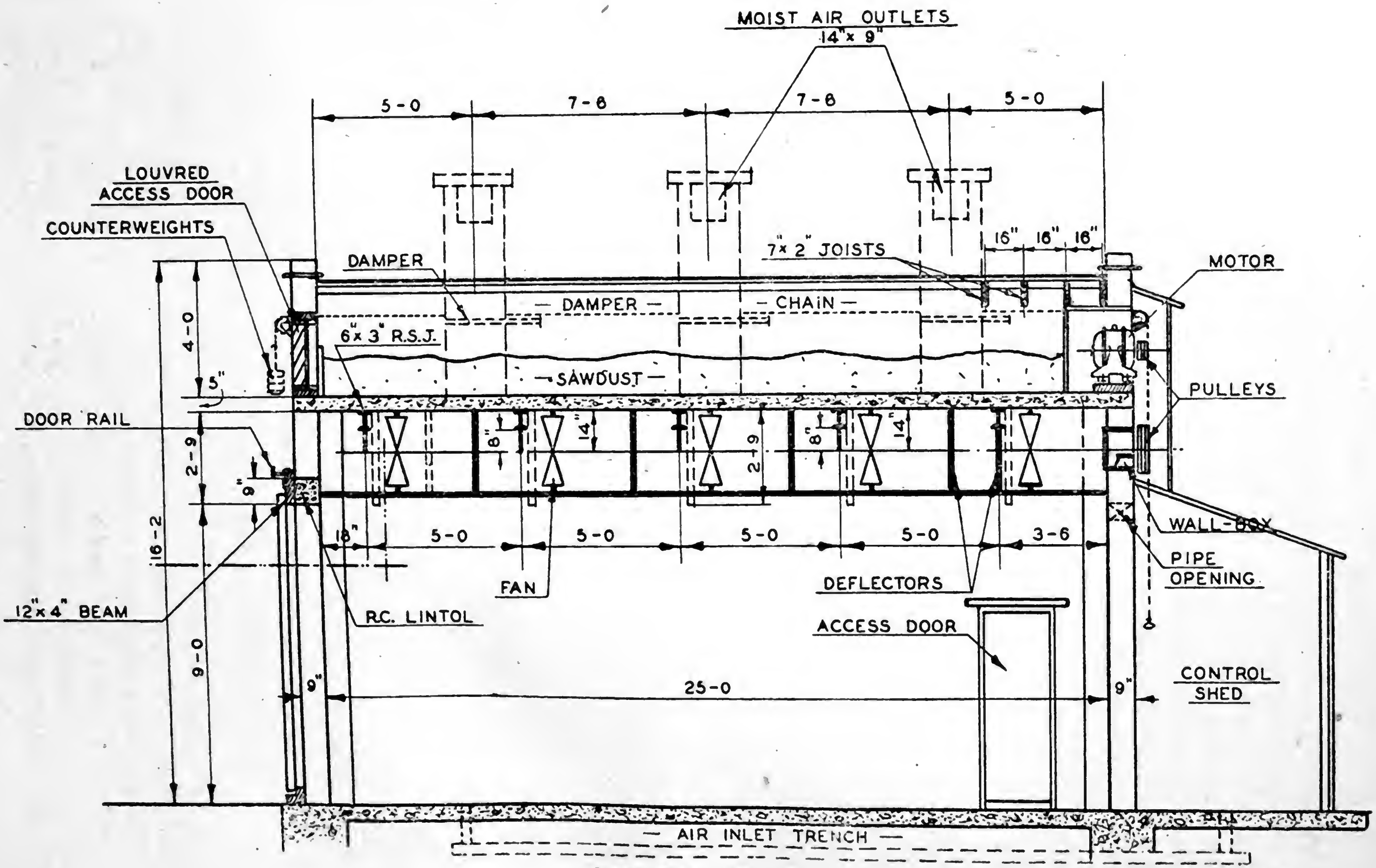


Cross-section

(Courtesy of G. F. Wells

FIG 17A. Cross circulation overhead internal-fan kiln.

At one time—and there are still advocates of the practice—it was regarded as highly important that the timber should be 'steamed' for some hours before drying was begun. 'Steaming' means subjecting the timber to hot saturated air. It was considered that steaming served to heat the timber right through and to relieve all stresses present. In the author's opinion



Longitudinal section

(Courtesy of G. F. Wells

FIG. 17B. Cross circulation overhead internal-fan kiln.

'steaming' in this sense is pure waste of time. Let us just consider what happens when a load of green timber is heated up to the temperature considered the correct one at which to commence drying. As the timber is green, fairly moist air would be employed to heat the kiln-chamber. The warm, moist air will enter the cold timber stack and will immediately become cooled. As it cools it will become saturated and will therefore heat up the timber without any appreciable drying. And so the process of warming up will continue until the timber is nearly as warm as the circulating air.

The air which now enters the stack will not be cooled appreciably and so will be able to evaporate some moisture before becoming saturated. Drying will now begin.

If saturated air had been employed during the warming process, moisture would have been deposited on the timber until it (the timber) had attained the temperature of the air. As the timber probably rarely attains the air temperature—unless this is suddenly dropped—it follows that steaming with saturated air nearly always implies the deposition of moisture.

If the timber is partially seasoned, on the other hand, steaming is likely to bring about just those stresses it is supposed to relieve. Moisture deposited on timber the surface of which is below about 25 per cent. moisture content will tend to cause swelling. This may be resisted by the core of the timber and stresses may develop.

In the author's opinion, then, the best plan is to warm up the kiln, maintaining the humidity appropriate to the moisture content of the timber. This is given in the left-hand column of the schedules below.

The humidities to be employed in drying different species of timber vary surprisingly little. Thus 80 to 85 per cent. is the starting range for nearly all green timbers, and the finishing range, though naturally depending on the final moisture content required, lies between 40 and 50 per cent.

The actual manual operations required to produce the temperature and humidity considered suitable are dealt with in the next chapter, and at this stage we must assume that by adjusting the supply of heat we can obtain any temperature we wish, and by controlling the amount of live steam ejected from the spray system we can have any humidity desired.

So the kiln is warmed at the appropriate humidity until the correct temperature is reached, and then settles down. The kiln samples are weighed daily until their weights indicate that the moisture content has fallen to the next point in the schedule. Then a change is made either by lowering the humidity slightly, or raising the temperature a little, or both. So on to the next moisture content given in the schedule, when the conditions are again changed, and so on till the timber is dry.

When is the Timber Dry? Supposing there are four sample pieces built into a kiln timber stack. Two on one side and two on the other. Let us assume also that we are aiming at a final moisture content of 10 to 12 per cent. If the air circulation is not reversible—or has not been reversed—the samples on the air-inlet side will inevitably dry a little faster than those on the air-outlet side of the stack. When one of these has dried to, say, 10 per cent. moisture content, the other may have a content of 14 per cent., while the two samples on the air-outlet side may have contents of, say, 15 and 16 per cent. Let us assume also that the kiln conditions are: Temperature, 158° F. (70° C.); Humidity, 45 per cent. These conditions refer, of course, to the state of the air as it enters the timber stack.

Clearly some of the timber in the kiln is behaving like the first sample and is therefore dried to the required moisture content, though it should be remembered that as the timber dries from the surface the outside layers will probably be some 5 per cent. below this figure, while the mosture content of the centre may be something of the order of 12 to 16 per cent. or even higher, depending on the species and on the thickness and various other factors. Still, that portion of the load represented by that particular sample piece is, on the average, dry. If the present conditions are maintained all parts of the load will continue to dry, so that by the time the wettest sample has dried to about 12 per cent. the driest will be considerably below the required value.

Now over-dried timber will give just as much trouble in service as under-dried material, so that to continue to operate the kiln at the present conditions would be very undesirable.

The solution of this problem, or indeed of any other similar one, can be found by applying the information contained in the chart shown on page 95 (Fig. 27).

This chart gives the relationship—the approximate relationship—between the moisture content of timber and the surrounding atmospheric conditions. That is to say, if a piece of timber is left in an atmosphere of a certain temperature and humidity it will eventually dry to a certain definite moisture content. This is known as the equilibrium moisture content.

The vertical scale of the chart is divided into units of moisture content from 0 to 25 per cent. The horizontal scale is divided in units of relative humidity from 0 to 100 per cent. The seven curves are isothermals or lines of equal temperature. The point where an isothermal cuts a humidity ordinate represents the moisture content of timber in equilibrium with that temperature and that humidity. For temperatures intermediate to those shown interpolation must be adopted.

In the case in point the temperature was 158° F. (70° C.) and the humidity 45 per cent. Thus the equilibrium moisture content is about 5½ per cent.

If the kiln was left running at these conditions all the timber would eventually dry to about 5 per cent. moisture content. But we do not desire a moisture content below 10 per cent. Therefore we have to raise the humidity (leaving the temperature at the same point) to give us equilibrium conditions of about 10 per cent. moisture content. It will be seen from the chart that the 10 per cent. moisture content line cuts the 70° C. temperature curve at 78 per cent. relative humidity. This, then, is the humidity which has to be maintained till all the timber has dried to at least 12 per cent. moisture content.

Naturally, raising the humidity means that the pieces in the stack above 10 per cent. moisture content will dry considerably slower than they were doing just before. But the only possible compromise is to raise it.

The pieces which had already dried to an average moisture content of about 10 per cent. actually benefit from the more humid conditions because the over-dried outside layers pick up a little moisture while the insufficiently seasoned centre portions continue to dry. If the equilibrium conditions are maintained long enough all the timber in the kiln will be uniformly dried to about 10 per cent. In practice, of course, the equilibrium conditions are only maintained long enough to reduce the moisture content of the wettest piece to about 12 per cent., which will

probably mean that that piece is rather wetter than 12 per cent. in the centre. But the very fact that this high humidity treatment causes slow-drying means that no piece will be dried to 12 per cent. on the average with an excessively wet centre.

Incidentally, the treatment tends to relieve all stresses in the wood so that there need be no fear of subsequent warping as a result of casehardening when the timber is worked into its final form.

Even if, by some coincidence, all the sample pieces in a load dried to the required figure simultaneously, some final high humidity treatment is very advisable to release stresses and to obviate uneven distribution of moisture.

The reader should now be in a position to understand the proper application of the drying schedules given below.

Kiln-Drying Schedules

The quality of timber varies so much that it is obviously impossible to indicate the most suitable conditions for all classes of material likely to be encountered. The drying schedules given are believed to be suitable for the average run of material available in this country and are intended as a guide. Experience with drying any particular class of material will enable an operator to develop his own schedules modifying those given below as results dictate. In general the schedules are conservative and some stiffening up should be possible. This will probably generally take the form of raising the temperature rather more rapidly, though in some cases it may be found possible to employ lower humidities.

Again, the schedules are designed for use with random sawn material, and where only quarter-cut timber is dried severer conditions can be applied with safety. In formulating the schedules due regard has been paid to the usual thicknesses and uses, and special sizes with special purposes in view will almost certainly require modified schedules.

In this country, at any rate, mere speed in drying is generally of less importance than good drying, that is, drying without undue waste. Some warping and probably a little splitting is almost inevitable, but if the schedules given are adhered to

faithfully undue degrade need not be feared, and reasonably fast drying will result if the kiln is satisfactory.

A list of timbers in general use in this country is given below. Opposite each timber is a letter and this indicates the schedule to be employed.

The schedules all start with the conditions suitable for green material, but if the timber to be dried is already partially seasoned—as occurs so frequently in the case of imported timbers—then the schedule should be picked up at the appropriate moisture-content phase. An actual example may make this clear: Supposing a load of American oak is to be dried and a number of tests have shown that the moisture content varies between 28 and 23 per cent. The correct conditions at which to commence drying are therefore those corresponding to '30 per cent. moisture content' in the schedule applicable to Oak (Schedule C), viz. 115° F. (46° C.), and 65 per cent. humidity. After warming the kiln at about 65 per cent. humidity to 115° F., no change should be made till the wettest sample piece on the air-inlet side has dried to 25 per cent. moisture content. If it so happens that the samples placed on that side of the stack were rather drier than some of the others, no change should be made till they have dried a little below the 25 per cent. figure.

If this particular parcel of oak was destined for cabinet-making, the moisture content should be reduced to about 12 per cent. When one sample piece has dried to 12 per cent. the humidity should be raised to about 70 per cent. After a day or so at these conditions (135° F., 70 per cent. humidity) the kiln could be cooled and the timber withdrawn.

There is no harm in withdrawing hot timber from a kiln provided it is really dry (12 per cent. moisture content or less) and the final temperature employed is not very high (say over 160° F.).

LIST OF TIMBERS IN COMMON USE AND DRYING SCHEDULES APPLICABLE *

Species.	*Schedule.*	*Species.*	*Schedule.*
Alder	F	Mahogany, Honduras	E
Ash	E	Mandioqueira	D
Beech	E	Mansonia	B
Birch	E	Maple, Hard	E
Box	C	Oak	C
Cedar, Western Red	G	Obeche	G
Chestnut, Sweet	B	Peroba Rosa	E
Ebony	E	Pine, Columbian	F
Elm	A	,, Corsican	H
Fir, Douglas	F	,, Pitch	D
,, Silver	G	,, Parana	D
Freio	E	,, Scots	H
Greenheart	C	,, Western White	H
Gurjun	E	Poplar	E
Hemlock	F	Seraya, Red	E
Hornbeam	E	,, White	E
Iroko	E	Spruce, Common	G
Jarrah	C	,, Sitka	F
Keruing	F	Sycamore	A
Larch, European	G	Teak	F
Lime	F	Walnut, African	E
Louro Vermelho	E	,, American	E
Mahogany, African	A	,, Australian	G
		,, European	E

The first schedule is a special low-temperature one suitable for timbers which must not darken in drying, and for those which have a pronounced tendency to warp.

SCHEDULE A

Moisture Content of the timber on the air-inlet side at which changes are to be made.	*Temperature (Dry Bulb).*		*Wet-Bulb Temperature.*		*Relative Humidity.*
	° *F.*	° *C.*	° *F.*	° *C.*	
Green	105	40·5	99	37·2	80%
60%	105	40·5	97	36·3	75%
40%	110	43·4	100	38·0	70%
35%	110	43·4	98	37·0	65%
30%	110	43·4	96	36·0	60%
25%	115	46·1	99	37·2	55%
20%	115	46·1	96	36·1	50%
18%	120	48·7	100	38·1	50%
16%	120	48·7	98	36·8	45%
14%	120	48·7	96	35·5	40%

* The schedules apply to timber up to about 3 in. thick. Thicker sizes will

require higher humidities throughout. Experience during the war suggests that slightly higher humidities may be employed with advantage in the early stages when drying poor quality home grown timbers.

Temperatures are quoted in Degrees Fahrenheit and Degrees Centigrade because, though the Fahrenheit scale is the one in general use, the Centigrade scale is already preferred by some. The Fahrenheit temperatures are quoted to the nearest degree only as that is sufficiently accurate for this particular purpose. It would not be quite accurate enough to quote the Centigrade temperatures to the nearest degree so these are quoted to the nearest tenth of a degree.

The next schedule is intended for use with timbers which dry very slowly, but which are not particularly prone to warping.

SCHEDULE B

Moisture Content of the timber on the air-inlet side at which changes are to be made.	*Temperature (Dry Bulb).*		*Wet-Bulb Temperature.*		*Relative Humidity.*
	° *F.*	° *C.*	° *F.*	° *C.*	
Green . .	120	48·8	115	46·0	85%
60% . . .	125	51·7	118	47·9	80%
40% . . .	130	54·4	123	50·4	80%
35% . . .	140	60·0	132	55·8	80%
30% . . .	150	65·6	140	59·8	75%
25% . . .	160	71·1	149	65·0	75%
22% . . .	170	76·6	156	68·8	70%
20% . . .	180	82·2	165	73·9	70%
18% . . .	180	82·2	162	72·4	65%
16% . . .	180	82·2	159	70·7	60%

The next schedule (Schedule C) is to be used with refractory timbers. It is the mildest schedule of all, and consequently cannot be expected to produce rapid drying. Timbers, such as oak which are particularly liable to split, especially when relatively wet, have to be dried to a schedule of this nature.

Even good-quality material cut from refractory species has to be dried to a mild schedule to begin with. But once the moisture content has fallen to, say, 20 to 25 per cent., higher temperatures than those given here can often be employed with advantage. The use of higher temperatures requires caution, however, and operators are strongly advised to make very gradual increases until a limiting treatment is eventually attained.

The use of low temperatures with wet timber almost inevitably leads to considerable growths of mould on the surfaces of the timber, the piling sticks and even the walls and equipment of the kiln. Such mould growths do not, as a rule, do any harm to

the timber, but their presence impedes the air circulation and the evaporation of moisture. They should, therefore, be killed off. The method of doing this is described a little later on page 62.

SCHEDULE C

Moisture Content of the timber on the air-inlet side at which changes are to be made.	*Temperature (Dry Bulb).*		*Wet-Bulb Temperature.*		*Relative Humidity.*
	° F.	*° C.*	*° F.*	*° C.*	
Green . .	105	40·5	101	38·0	85%
60% . . .	105	40·5	99	37·2	80%
40% . . .	110	43·3	102	38·7	75%
35% . . .	110	43·3	100	37·9	70%
30% . . .	115	46·1	103	39·5	65%
25% . . .	120	48·8	105	40·8	60%
20% . . .	125	51·7	107	41·8	55%
18% . . .	130	54·4	109	43·0	50%
16% . . .	135	57·1	111	43·8	45%
14% . . .	140	60·0	114	46·2	45%

We now proceed to schedules of gradually increasing severity. Schedules D to H produce more rapid drying than those above, but naturally enough cannot be applied to very refractory timbers.

SCHEDULE D

Moisture Content of the timber on the air-inlet side at which changes are to be made.	*Temperature (Dry Bulb).*		*Wet-Bulb Temperature.*		*Relative Humidity.*
	° F.	*° C.*	*° F.*	*° C.*	
Green . .	110	43·4	105	40·8	85%
60% . . .	110	43·4	104	40·0	80%
40% . . .	115	46·1	107	41·5	75%
35% . . .	115	46·1	105	40·5	70%
30% . . .	120	48·7	108	42·0	65%
25% . . .	125	51·6	110	43·3	60%
20% . . .	130	54·4	112	44·4	55%
18% . . .	135	57·2	113	45·4	50%
16% . . .	140	60·0	114	46·2	45%
14% . . .	145	62·7	115	46·7	40%

SCHEDULE E

Moisture Content of the timber on the air-inlet side at which changes are to be made.	*Temperature (Dry Bulb).*		*Wet-Bulb Temperature.*		*Relative Humidity.*
	° *F.*	° *C.*	° *F.*	° *C.*	
Green . .	120	48·7	115	45·9	85%
60% . . .	120	48·7	113	45·0	80%
40% . . .	125	51·7	116	46·8	75%
35% . . .	125	51·7	114	45·7	70%
30% . . .	130	54·4	116	47·0	65%
25% . . .	135	57·2	118	48·0	60%
20% . . .	140	60·0	120	49·2	55%
18% . . .	145	62·7	122	50·1	50%
16% . . .	150	65·5	123	50·7	45%
14% . . .	155	68·3	123	50·7	40%

SCHEDULE F

Moisture Content of the timber on the air-inlet side at which changes are to be made.	*Temperature (Dry Bulb).*		*Wet-Bulb Temperature.*		*Relative Humidity.*
	° *F.*	° *C.*	° *F.*	° *C.*	
Green . .	130	54·4	121	49·3	75%
35% . . .	135	57·2	123	50·7	70%
30% . . .	140	60·0	125	52·1	65%
25% . . .	145	62·7	127	53·1	60%
22% . . .	150	65·5	129	54·2	55%
20% . . .	155	68·3	131	54·9	50%
18% . . .	160	71·1	132	55·4	45%
16% . . .	165	73·8	132	55·7	40%
14% . . .	170	76·6	136	58·0	40%

SCHEDULE G

Moisture Content of the timber on the air-inlet side at which changes are to be made.	*Temperature (Dry Bulb).*		*Wet-Bulb Temperature.*		*Relative Humidity.*
	° *F.*	° *C.*	° *F.*	° *C.*	
Green . .	140	60·0	133	55·8	80%
60% . . .	140	60·0	130	54·6	75%
40% . . .	145	62·7	135	57·1	75%
35% . . .	145	62·7	132	55·9	70%
30% . . .	150	65·6	134	57·2	65%
25% . . .	155	68·3	136	58·5	60%
22% . . .	160	71·1	138	59·0	55%
20% . . .	165	73·9	139	59·7	50%
18% . . .	170	76·6	144	62·0	50%
16% . . .	175	79·4	148	64·5	50%
14% . . .	180	82·2	152	66·9	50%

SCHEDULE H

Moisture Content of the timber on the air-inlet side at which changes are to be made.	*Temperature (Dry Bulb).*		*Wet-Bulb Temperature.*		*Relative Humidity.*
	° *F.*	° *C.*	° *F.*	° *C.*	
Green . .	150	65·6	142	61·1	80%
30% . . .	155	68·3	144	62·3	75%
25% . . .	160	71·1	146	63·7	70%
22% . . .	165	73·9	148	64·7	65%
20% . . .	170	76·6	150	65·7	60%
18% . . .	175	79·4	151	66·4	55%
16% . . .	180	82·2	152	66·9	50%
14% . . .	185	85·0	153	67·2	45%

Anyone comparing the schedules listed here with those recommended in the country of origin of some of the imported timbers will at once be struck by the milder conditions (lower temperatures and higher humidities) set down here.

In the author's experience the home operator is prepared to spend a little more time over the drying process to ensure a minimum of degrade. In the country of origin the cost of the timber is much lower than here, and a considerable amount of degrade is presumably justified if rapid drying can be secured.

Steaming to Kill Mould Growths

Moulds flourish at temperatures necessitated in the early stages of drying all but the most tolerant green timbers. Moreover, high air humidities are ideal for their development.

When a vigorous growth occurs in a kiln charge, steps should be taken to stop activity.

The simplest way is to make use of a short spell of high-temperature treatment. As raising the temperature might also prove harmful to the timber in the kiln, it is necessary to raise the humidity of the air too. At all moisture contents above about 30 per cent. saturated air should be employed when raising the temperature. As both conditions can be fulfilled by turning on the steam-spray jets, the process has come to be known as 'steaming'. Using the steam-sprays, the kiln temperature should be raised to about 160° F. (71° C.), when nearly all moulds will be killed. The high temperature should be maintained for about an hour, when the kiln conditions can be brought back to normal. The dead mould dries up and blows

away, but fresh growths may develop in a day or two, when 'steaming' must be resorted to again.

When the moisture content of timber is below about 30 per-cent. the conditions are not usually suitable for mould development, but should it occur the temperature should be raised as before, maintaining a humidity of about 80 per cent.

Drying Times

We now come to the vexed question of how long timber takes to dry in a kiln.

So much depends on the quality of the timber, on the efficiency of the kiln, and on the skill of the operator, that it is quite impossible to quote drying times with any exactitude.

The final state required is also a factor of considerable influence. If uniformly dry timber with a minimum of warping and splitting is desired, the drying time will obviously be considerably greater than when a fair measure of warping and checking is of no importance, and when wet patches in the centre of the pieces is no objection. The final moisture content desired must also influence the drying time quite apart from the actual range of moisture content over which the timber is dried. To dry from 30 to 20 per cent. moisture content will take considerably less time than to dry from 20 to 10 per cent.

Bearing all this in mind, it will be clear that to quote drying times to any close degree would only lead to disappointment in many cases.

As a very approximate guide, however, the following figures may be given: If an efficient forced-draught kiln is employed, 2 inch thick planks will require:

Ordinary softwoods:		
Green	to 10% moisture content . . .	1 to 2 weeks
Air-dried	,, ,, ,, . . .	1 week or less
Hardwoods (depending on the species):		
Green	to 10% moisture content . . .	3 to 12 weeks
Air-dried	,, ,, ,, . . .	1 to 4 weeks

With a good natural-draught kiln the times may be as much as half as long again.

One point brought out by the above is the big saving in time effected if the timber is previously air-dried to a moisture content of about 20 per cent. Apart from the assurance that conditions are always under control, kiln-drying does not offer a very

great advantage over air-drying in the early stages. For this reason, particularly with slow-drying timbers, it is usually sound economics to allow a few months air-drying before loading into the kiln. Admittedly this means handling the load twice, unless bogies are available in sufficient numbers, or some such device as a lifting truck is used, whereby the stack can be transferred from the air-seasoning yard to the kiln with a minimum of labour.

Even if the timber has to be taken down from one stack and piled again in a kiln, it will usually pay to do so if a saving of at least a week in the kiln can be effected. Of course, if there is no great demand on the kilns and steam and power are cheap, the longer period in the kiln may be justified.

It is very difficult to discuss the economics of kiln-drying as so many factors apply, but it is significant that it is very rare to hear of any operator kiln-drying hardwoods of 2 inches thick or over from the green state.

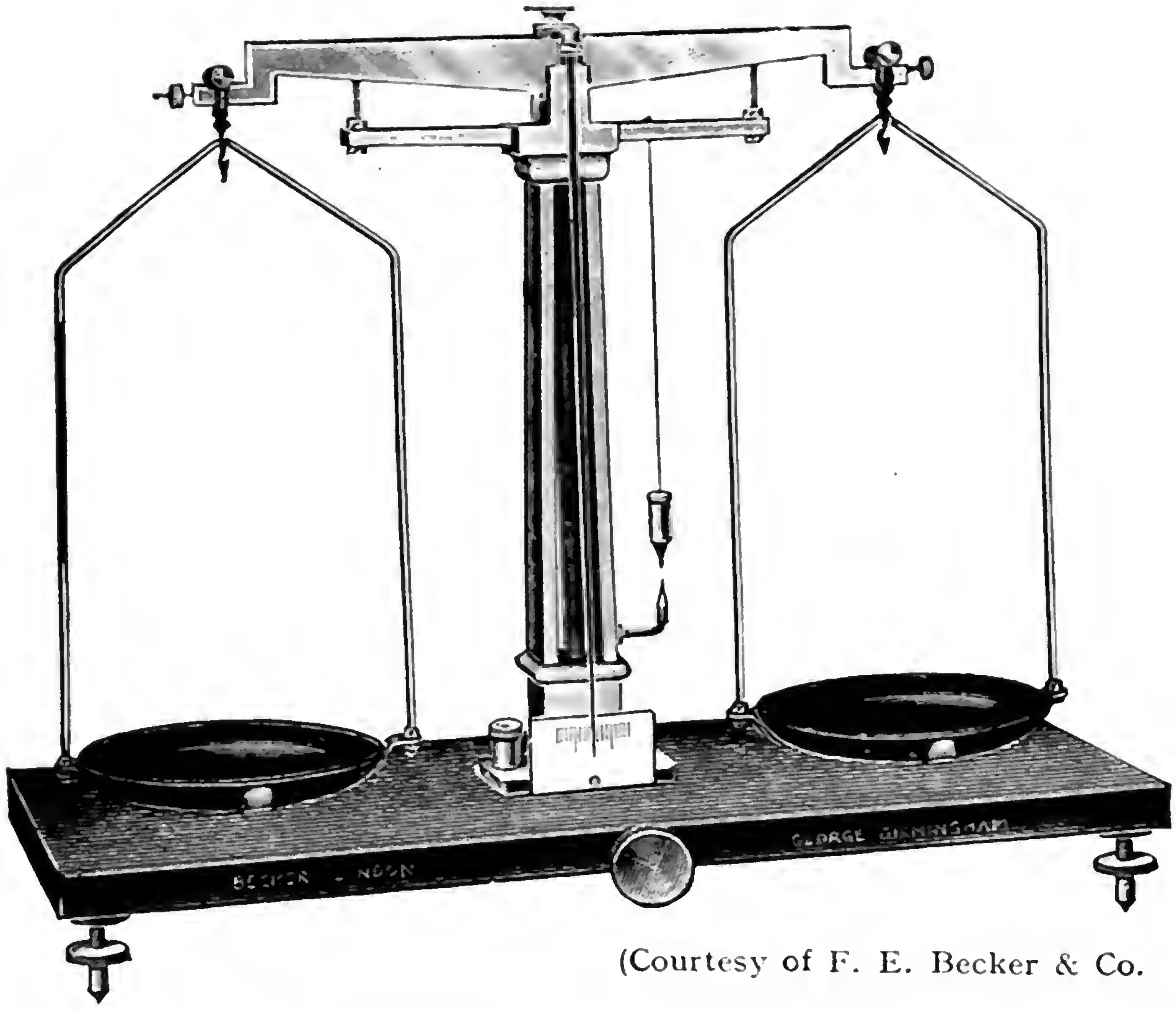
Where the timber is imported already sawn—even though it is not fully air-seasoned—double handling would hardly ever be justified.

Kiln Apparatus and Instruments and Their Use

Reference has been made to moisture content and its determination, to the use of temperatures and humidities and their control, and to air velocities and circulation. The apparatus and instruments required to determine these qualities are very varied, but some brief descriptions are given below.

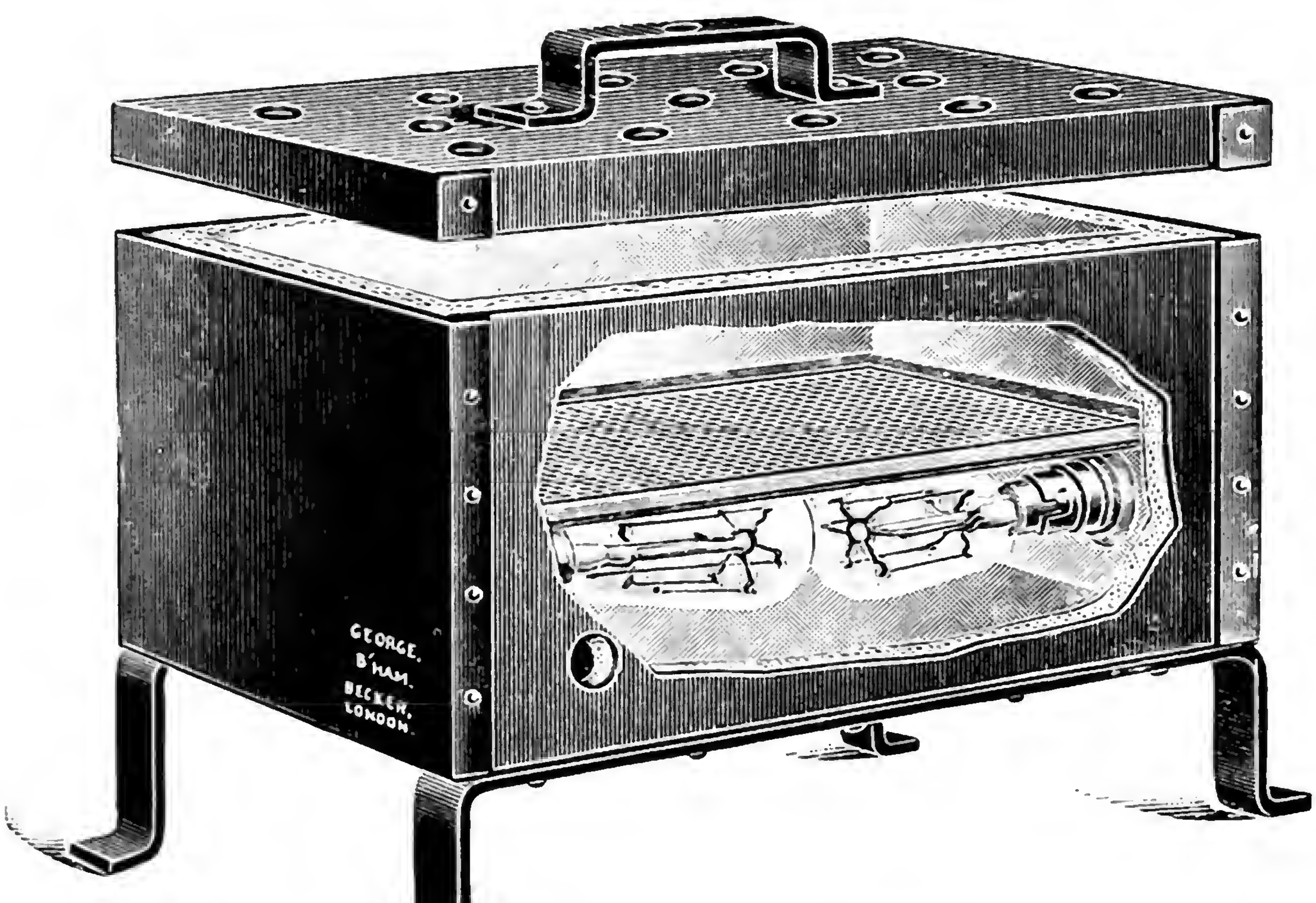
Apparatus for the Determination of Moisture Content.

The simplest and in many ways the best, though not the quickest, methods of determining the moisture content of timber is to actually cut a sample out of the piece to be tested, dry it in an oven and weigh it before and after drying. The weighings can be made on an ordinary Student's Balance (Fig. 18). A balance of this type can be purchased from any firm supplying laboratory equipment. If loose weights are regarded as a disadvantage, special balances having sliding weights—on the principle of the steelyard—can be obtained. If it is desired to simplify the calculation involved in determining the moisture content from the initial and final weights of the sample, a balance of the type shown in Fig. 19 can be purchased. (This



(Courtesy of F. E. Becker & Co.

FIG. 18. Student's balance suitable for use in moisture-content determination.



Courtesy of F. E. Becker & Co.

FIG. 20. Simple electric-bulb oven for moisture-content determination.

[Courtesy of Marconi Instruments Ltd.)

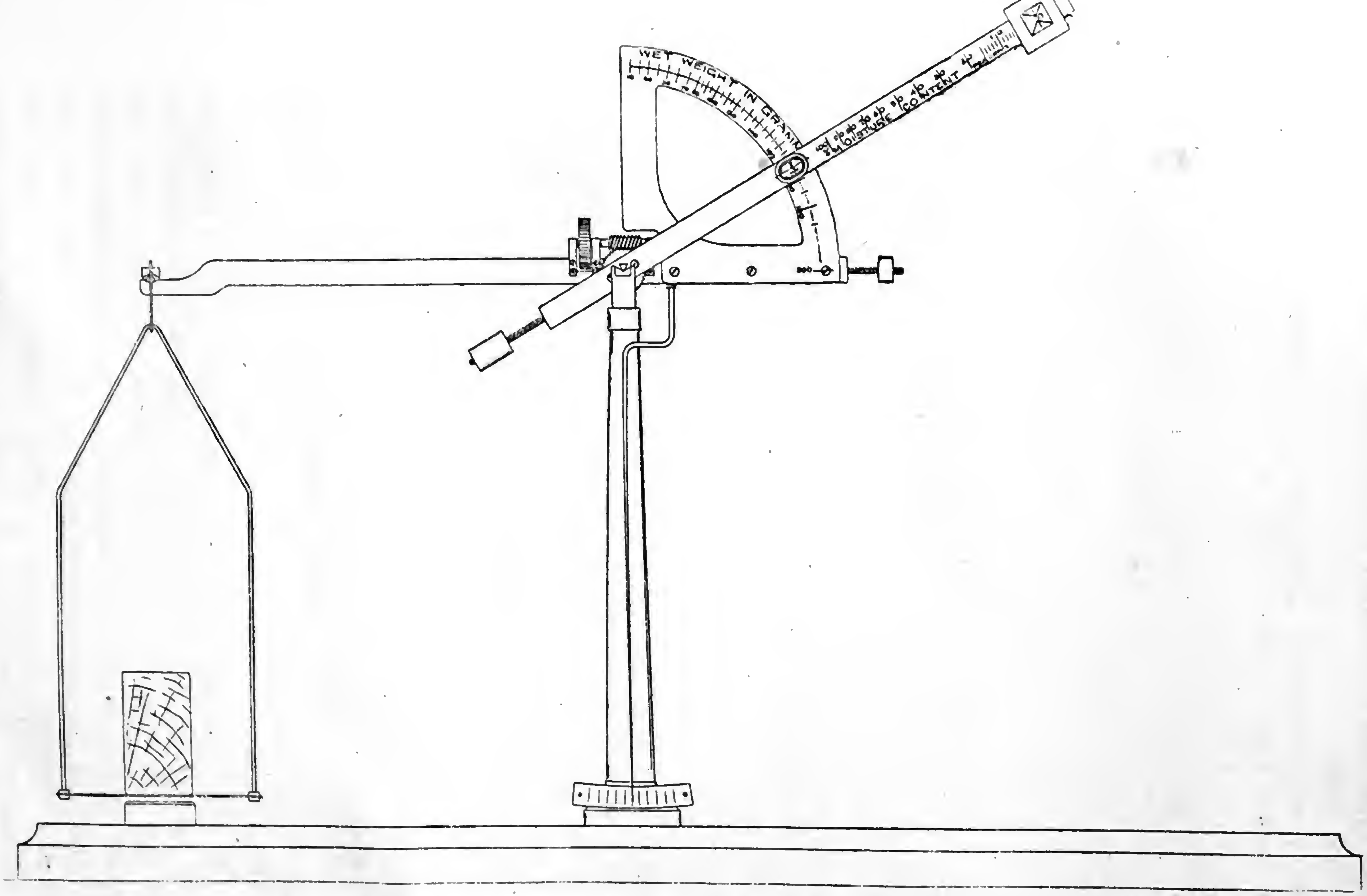
FIG. 21. A meter for determining the moisture content of timber electrically.

particular type was developed by the author and is shown here for the first time).

Many types of oven for drying out the samples are available, but the simple type shown in Fig. 20, which was developed by the U.S. Forest Products Laboratory, is perfectly satisfactory and has the advantage of being cheap to construct and safe and foolproof. Samples should be dried at a temperature of just above the boiling-point of water (212° F., 100° C.) and in the oven shown the temperature is regulated, coarsely by the wattage of the electric light bulbs used, and more finely by regulating the ventilation. This is done by corking up or uncorking the holes in the top of the oven until the right temperature is attained. Samples about ½ inch thick (that is along the grain) will dry out in this oven in a few hours.

The oven-drying method of determining the moisture content of timber has much to recommend it because the method is positive and direct. The actual moisture present is evaporated in much the same way that it will be evaporated if the timber is to be kiln-dried. The whole cross-section of a piece of timber can be tested, or subdivisions of the cross-section can be tested separately, enabling the distribution of moisture to be discovered. It is true that very oily or resinous timbers lose something more than moisture in oven-drying, but the amount lost is generally so small that it can be neglected for most purposes.

Within recent years instruments have been developed which give an almost instantaneous reading of the moisture content. These are usually called moisture meters. A good example of this type of instrument is shown in Fig. 21. All operate electrically and really measure either the electrical resistance or the electrical capacity of the timber. These properties vary with the amount of moisture present, and so it is only necessary to calibrate the instrument in terms of moisture content. Unfortunately, the electrical properties of wood itself vary so that calibrations are generally required for each species. Moreover, within any one species, or indeed within any one tree, the properties vary so that a moisture meter can never attain quite the accuracy of the oven-drying method. Nevertheless, they are sufficiently accurate for a good many purposes and have the great advantage of speed and of doing no damage to the piece of wood tested. No moisture meter yet developed is capable of



(*Copyright reserved by the Author*

FIG. 19. Moisture content calculating balance developed by the author.

To determine the moisture content of a sample it is placed on the pan and the beam balanced by rotating the right-hand arm of the balance by means of the worm and pinion, when the sliding jockey weight is at the zero position on the moisture-content scale. The sample is then oven dried and again placed on the pan. Balance is now effected by sliding the jockey weight to the left. The moisture content per cent. is read off at the position of the jockey weight.

If it is desired to determine the moisture content of a series of samples at the same time, the wet weight of each sample is determined by noting the reading of the magnifying cursor on the graduated quadrant when the beam is balanced. When the sample is dry it will first be necessary to reset the right-hand arm to the wet-weight position and then obtain a balance by sliding the jockey weight to the left.

detecting the distribution of moisture within the wood, and if it is desired to know this it is necessary to cut up a piece and test various zones in the cross-section in much the same way as when determining the distribution of moisture by the oven-drying method.

Really a moisture meter is best used in conjunction with the oven method, a few pieces being tested by oven-drying and almost every other piece being tested with the meter.

Measurement of Temperature and Humidity.

Most people have a very good idea of how to measure temperature, but probably have only a vague idea of the determination of the relative humidity of the air.

Temperature is conveniently measured in a kiln with the ordinary mercury-in-glass thermometer suspended at some point where a light can be shined upon it and where it can be seen through a port in the kiln door or walls. A refinement, of course, is to employ a distant thermometer, or better still a recording distant thermometer, which can be fixed outside the kiln, the thermometer bulb being placed anywhere within the kiln where it is desired to measure the temperature.

The humidity of the air can be measured in several ways, but the only satisfactory method for kiln use is by the wet and dry bulb hygrometer.

In its simplest form the wet and dry bulb hygrometer consists of two ordinary thermometers suspended side by side. One of the thermometers has its bulb surrounded by a cotton wick which is kept wet. The air passing the thermometer bulb evaporates moisture from the wick. The evaporation of moisture requires the expenditure of heat energy and so the thermometer bulb is cooled. The greater the rate of evaporation the more the thermometer bulb is cooled. Tables have been prepared enabling the humidity to be reckoned when the temperature (the dry-bulb thermometer reading) and the wet-bulb thermometer reading are known. Table II has been drawn up for use with thermometers divided in degree Fahrenheit, while Table III is for use with Centigrade thermometers.

The chart shown in Fig. 22 enables the relative humidity to be determined without first finding the wet-bulb depression, that is without subtracting the wet-bulb thermometer reading from the dry-bulb thermometer reading. To use this chart obtain a

TABLE II (° F.)

TABLE OF RELATIVE HUMIDITY OF PER CENT. OF SATURATION

Dry Bulb. ° F.	Difference between Readings of Wet and Dry Bulbs in Degrees Fahrenheit.																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	22	24	26	28	30	32	34	36
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38											
85	96	92	88	84	80	76	73	70	66	63	59	56	53	50	47	44	41	38										
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41	39									
95	96	93	89	85	82	79	75	72	69	66	63	60	57	54	52	49	46	43	42	38								
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46	44	41	37							
102	96	93	89	86	83	80	77	74	71	69	65	62	59	57	54	52	49	47	45	43	38							
104	96	93	90	86	83	80	77	74	71	69	65	63	60	58	55	52	50	48	46	43	39	35						
106	96	93	90	87	83	80	77	74	72	69	66	63	60	58	55	53	51	48	46	44	40	36						
108	96	93	90	87	84	81	78	75	72	70	66	64	61	59	56	54	51	49	47	45	41	37						
110	96	93	90	87	84	81	78	75	72	70	67	64	62	60	57	55	52	50	48	46	41	37						
112	96	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	53	51	49	47	42	38						
114	97	93	90	87	84	81	78	75	73	71	68	65	63	61	58	56	53	51	49	47	43	39						
116	97	93	90	88	84	82	79	76	74	71	68	66	63	61	59	56	54	52	50	48	44	40	36					
118	97	93	91	88	85	82	79	76	74	71	68	66	64	62	59	57	54	53	51	49	44	41	37					
120	97	94	91	88	85	82	79	77	74	72	69	66	64	62	60	57	55	53	51	49	45	41	38					
122	97	94	91	88	85	82	79	77	75	72	69	67	65	63	60	58	56	54	52	50	46	42	38					
124	97	94	91	88	85	83	80	77	75	72	70	67	65	63	61	58	56	54	52	51	46	43	39					
126	97	94	91	88	86	83	80	78	75	73	70	68	65	64	61	59	57	55	53	51	47	43	40	37				
128	97	94	91	89	86	83	80	78	76	73	71	68	66	64	61	59	57	55	53	52	47	44	40	37				
130	97	94	91	89	86	83	80	78	76	73	71	68	66	64	62	60	58	55	54	52	48	44	41	38				
132	97	94	92	89	86	83	81	78	76	74	71	69	67	65	62	60	58	56	54	53	49	45	42	39				
134	97	94	92	89	86	84	81	79	76	74	71	69	67	65	63	61	59	57	55	53	49	46	42	39				

136	97	94	92	89	86	84	81	79	77	74	72	69	67	65	63	61	59	57	55	53	50	46	43	40	37			
138	97	94	92	89	86	84	81	79	77	74	72	70	68	66	63	62	60	58	56	54	50	47	43	40	37			
140	97	94	92	89	87	84	81	79	77	75	72	70	68	66	64	62	60	58	56	54	51	47	44	41	38			
142	97	94	92	89	87	84	82	80	77	75	73	70	68	66	64	62	60	58	57	55	51	48	44	42	39			
144	97	95	92	89	87	84	82	80	78	75	73	71	69	67	65	63	61	59	57	55	52	48	45	42	39			
146	97	95	92	90	87	85	82	80	78	75	73	71	69	67	65	63	61	59	57	56	52	49	45	43	40	37		
148	97	95	92	90	87	85	82	80	78	76	73	71	69	67	65	63	61	60	58	56	53	49	46	43	40	38		
150	98	95	92	90	87	85	82	80	78	76	74	72	70	68	66	64	62	60	58	57	53	49	46	43	41	38		
152	98	95	93	90	88	85	83	81	79	76	74	72	70	68	66	64	62	60	59	57	53	50	47	44	41	39		
154	98	95	93	90	88	85	83	81	79	77	74	72	70	68	66	65	62	61	59	57	54	50	47	44	42	39		
156	98	95	93	90	88	85	83	81	79	77	74	72	71	69	66	65	63	61	59	57	54	51	48	45	42	40		
158	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	63	61	60	58	55	51	48	45	43	40		
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62	60	58	55	52	49	46	43	41	38	
162	98	95	93	90	88	86	84	82	80	77	75	73	71	69	68	66	64	62	60	59	55	52	49	46	44	41	39	
164	98	95	93	91	88	86	84	82	80	78	75	73	72	70	68	66	64	62	61	59	56	52	49	47	44	41	39	
166	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68	66	65	63	61	59	56	53	50	47	44	42	39	
168	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68	67	65	63	61	60	56	53	50	47	45	42	40	
170	98	95	93	91	89	86	84	82	80	78	76	74	72	70	69	67	65	63	62	60	57	53	50	48	45	43	40	
172	98	95	93	91	89	86	84	82	81	78	76	74	73	71	69	67	66	64	62	60	57	54	51	48	46	43	41	38
174	98	95	93	91	89	87	84	83	81	78	76	75	73	71	69	67	66	64	62	61	57	54	51	49	46	43	41	39
176	98	96	93	91	89	87	85	83	81	79	77	75	73	71	70	68	66	64	63	61	58	55	52	49	46	44	42	39
178	98	96	93	91	89	87	85	83	81	79	77	75	73	72	70	68	66	64	63	61	58	55	52	49	47	44	42	39
180	98	96	93	91	89	87	85	83	81	79	77	75	73	72	70	68	67	65	63	62	58	55	52	50	47	45	42	40
182	98	96	93	91	89	87	85	83	81	79	77	75	74	72	70	68	67	65	63	62	59	56	53	50	48	45	43	40
184	98	96	93	92	89	87	85	83	82	79	77	76	74	72	70	69	67	65	64	62	59	56	53	50	48	45	43	41
186	98	96	94	92	90	87	85	83	82	80	78	76	74	72	71	69	67	66	64	62	59	56	53	51	48	46	43	41
188	98	96	94	92	90	87	85	84	82	80	78	76	74	73	71	69	68	66	64	63	59	57	54	51	49	46	44	41
190	98	96	94	92	90	88	85	84	82	80	78	76	75	73	71	69	68	66	65	63	60	57	54	51	49	46	44	42
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**

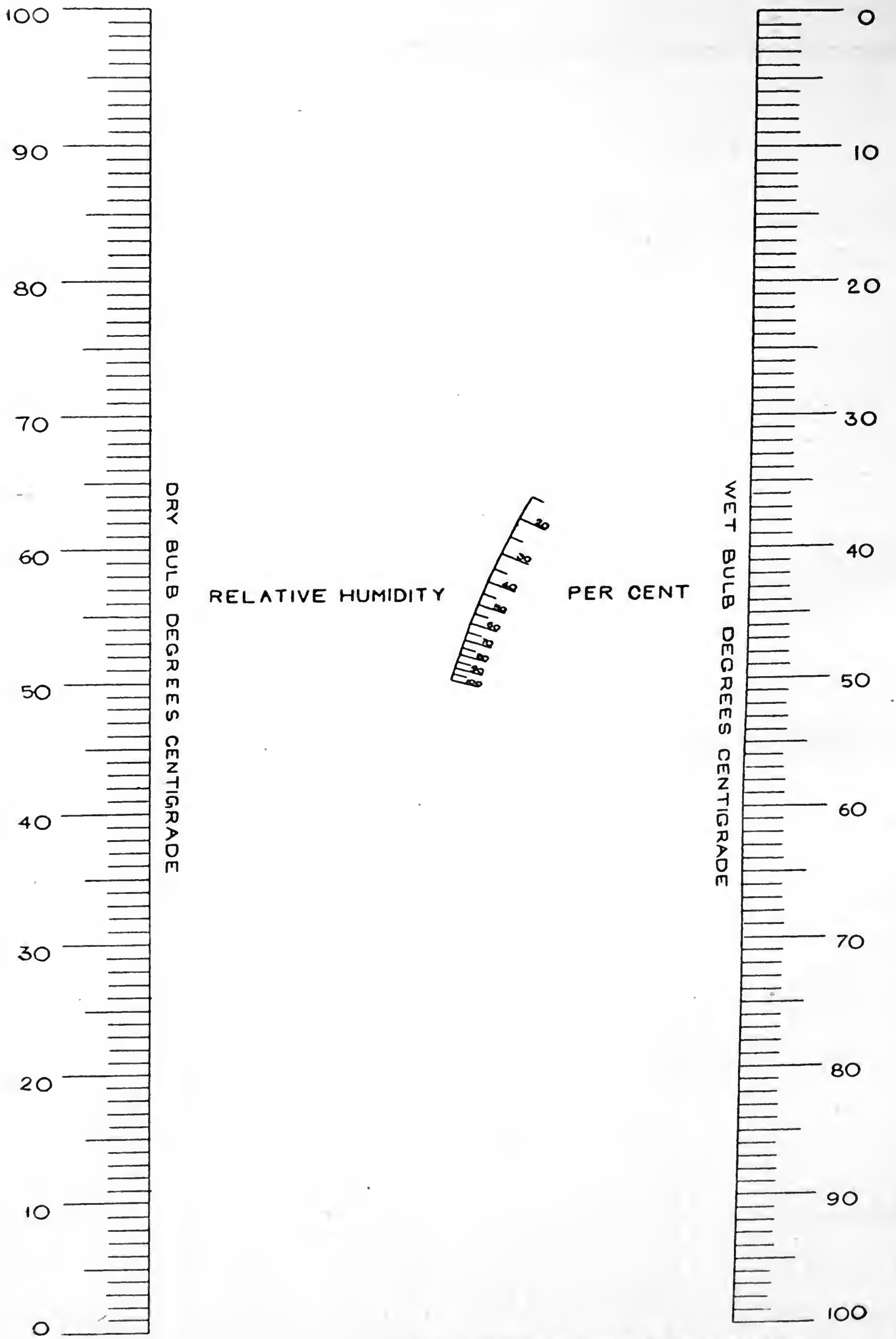
TABLE III (° C.)

Dry Bulb. ° C.	Difference between Readings of Wet and Dry Bulbs in Degrees Centigrade.																																								
	0·5	1·0	1·5	2	2·5	3	3·5	4	4·5	5	5·5	6	6·5	7	7·5	8	8·5	9	9·5	10	10·5	11	11·5	12	12·5	13	13·5	14	14·5	15	15·5	16	16·5	17	17·5	18	18·5	19	19·5	20	20·5	21
30	96	92	88	85	81	78	75	71	68	65	62	58	55	52	49	46	44	41	39																							
31	96	93	88	85	81	78	76	72	68	65	62	59	56	53	50	47	45	42	40																							
32	96	93	89	86	82	79	76	72	69	66	63	60	57	54	51	48	46	43	41																							
33	97	93	89	86	82	79	76	73	70	67	64	61	58	55	52	49	47	44	42	39																						
34	97	93	90	86	83	80	77	73	70	67	64	62	59	56	53	50	48	45	43	40	38																					
35	97	93	90	86	83	80	77	74	71	68	65	62	60	57	54	51	48	46	45	41	39																					
36	97	93	90	87	83	80	77	74	71	68	65	63	60	57	55	52	49	47	45	42	40	37																				
37	97	94	90	87	84	81	78	75	72	69	66	63	61	58	55	53	50	48	46	43	41	38																				
38	97	94	91	87	84	81	78	75	72	69	66	64	61	59	56	54	51	49	46	44	42	39																				
39	97	94	91	88	84	81	79	75	72	70	67	65	62	59	57	54	52	50	47	45	43	40	38																			
40	97	94	91	88	85	82	79	76	73	70	67	65	62	60	57	55	53	51	48	46	44	41	39	37																		
41	97	94	91	88	85	82	79	76	73	71	68	66	63	61	58	56	53	51	49	47	44	42	40	38																		
42	97	94	91	88	85	82	79	76	74	71	68	66	63	61	59	56	54	52	50	47	45	43	41	39																		
43	97	94	91	88	85	83	80	77	74	72	69	66	64	62	59	57	55	53	50	48	46	44	42	40	38																	
44	97	94	91	88	85	83	80	77	75	72	69	67	64	62	60	58	56	53	51	49	47	45	43	41	39																	
45	97	94	91	88	85	83	80	77	75	72	70	67	65	63	61	58	56	54	52	50	48	46	44	42	40	38																
46	97	94	91	89	86	83	80	78	75	73	70	68	65	63	61	59	56	54	52	50	48	46	44	42	41	39																
47	97	94	92	89	86	83	81	78	75	73	71	68	66	64	62	59	57	55	53	51	49	47	45	43	41	40	38															
48	97	94	92	89	86	84	81	78	76	74	71	69	66	64	62	60	58	56	54	52	50	48	46	44	42	40	38															
49	97	94	92	89	86	84	81	79	76	74	71	69	67	65	63	60	58	56	54	52	50	48	47	45	43	41	39															
50	97	94	92	89	86	84	81	79	76	74	72	69	67	65	63	61	59	57	55	53	51	49	47	45	44	42	40	38														
51	97	95	92	89	87	84	82	79	77	74	72	70	67	65	64	61	59	57	55	53	51	50	48	46	44	42	41	39														
52	97	95	92	89	87	84	82	79	77	75	72	70	68	66	64	62	60	58	56	54	52	50	48	47	45	43	41	40	38													
53	97	95	92	89	87	85	82	80	77	75	73	70	68	66	64	62	60	58	56	54	52	51	49	47	46	44	42	41	39													
54	97	95	92	90	87	85	82	80	77	75	73	71	68	67	65	63	60	59	57	55	53	51	49	48	46	44	43	41	39													
55	97	95	92	90	87	85	82	80	78	76	73	71	69	67	65	63	61	59	57	55	53	52	50	48	47	45	43	42	40	39												
56	97	95	93	90	87	85	83	80	78	76	74	72	69	67	65	64	62	60	58	56	54	52	50	49	47	46	44	42	41	40												
57	97	95	93	90	87	85	83	80	78	76	74	72	70	68	66	64	62	60	58	56	55	53	51	49	48	46	44	43	41	40												

T.D.

	0·5	1·0	1·5	2	2·5	3	3·5	4	4·5	5	5·5	6	6·5	7	7·5	8	8·5	9	9·5	10	10·5	11	11·5	12	12·5	13	13·5	14	14·5	15	15·5	16	16·5	17	17·5	18	18·5	19	19·5	20	20·5	21
58	97	95	93	90	88	85	83	81	78	76	74	72	70	68	66	64	62	60	59	57	55	53	51	50	48	47	45	43	42	41	39											
59	97	95	93	90	88	85	83	81	79	77	74	72	70	68	66	65	63	61	59	57	55	54	52	50	49	47	45	44	42	41	40											
60	97	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	63	61	59	57	55	54	52	51	49	48	46	44	43	42	40	39										
61	97	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	63	61	60	58	56	55	53	51	50	48	46	45	43	42	41	39										
62	97	95	93	90	88	86	84	81	79	77	75	73	71	69	67	65	64	62	60	58	56	55	53	52	50	49	47	45	44	43	41	40										
63	98	95	93	90	88	86	84	82	80	77	75	73	72	69	68	66	64	62	60	59	57	55	54	52	51	49	47	46	44	43	42	40										
64	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68	66	64	63	61	59	57	56	54	53	51	50	48	46	45	44	42	41	39									
65	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68	66	65	63	61	59	58	56	55	53	52	50	48	47	45	44	43	41	40									
66	98	95	93	91	89	86	84	82	80	78	76	74	72	70	68	67	65	63	61	60	58	56	55	53	52	50	49	47	46	45	43	42	41	39								
67	98	95	93	91	89	86	84	82	80	78	76	74	72	70	69	67	65	64	62	60	58	57	56	54	53	51	49	48	46	45	44	42	41	40	38							
68	98	95	93	91	89	87	84	82	80	78	76	75	73	71	69	67	66	64	62	60	59	57	56	54	53	51	50	48	47	46	44	43	42	40	39							
69	98	95	93	91	89	87	84	83	81	79	77	75	73	71	69	68	66	64	62	61	59	58	56	55	53	52	50	49	47	46	45	43	42	41	39							
70	98	95	93	91	89	87	85	83	81	79	77	75	73	71	69	68	66	64	63	61	59	58	56	55	53	52	50	49	48	46	45	44	42	41	40	39						
71	98	95	93	91	89	87	85	83	81	79	77	75	73	71	70	68	66	65	63	61	60	58	57	55	54	52	51	49	48	47	45	44	43	42	40	39						
72	98	96	93	91	89	87	85	83	81	79	77	75	73	72	70	68	67	65	63	62	60	59	57	56	54	53	51	50	49	47	46	45	43	42	41	39						
73	98	96	93	91	89	87	85	83	81	79	77	76	74	72	70	69	67	65	63	62	60	59	57	56	54	53	52	50	49	47	46	45	44	42	41	40						
74	98	96	93	91	89	87	85	83	81	79	78	76	74	72	70	69	67	65	64	62	61	59	58	56	55	53	52	51	49	48	46	45	44	43	42	40						
75	98	96	94	91	90	87	85	83	82	80	78	76	74	72	71	69	67	66	64	62	61	59	58	56	55	54	52	51	50	48	47	46	44	43	42	41						
76	98	96	94	92	90	87	85	84	82	80	78	76	74	73	71	69	68	66	64	63	61	60	58	57	55	54	53	51	50	49	47	46	45	44	42	41						
77	98	96	94	92	90	88	86	84	82	80	78	76	75	73	71	70	68	66	64	63	61	60	59	57	56	54	53	52	50	49	48	46	45	44	43	42	40	39				
78	98	96	94	92	90	88	86	84	82	80	78	77	75	73	71	70	68	66	65	63	62	60	59	57	56	55	53	52	51	49	48	47	45	44	43	42	41	40				
79	98	96	94	92	90	88	86	84	82	80	78	77	75	73	72	70	68	67	65	64	62	60	59	58	56	55	54	52	51	50	48	47	46	45	44	42	41	40				
80	98	96	94	92	90	88	86	84	82	80	79	77	75	73	72	70	69	67	65	64	62	61	59	58	56	55	54	53	51	50	49	47	46	45	44	43	42	40	39	38		
81	98	96	94	92	90	88	86	84	82	81	79	77	75	74	72	70	69	67	66	64	63	61	60	58	57	55	54	53	52	50	49	48	47	45	44	43	42	41	40	39		
82	98	96	94	92	90	88	86	84	83	81	79	77	75	74	72	71	69	67	66	64	63	61	60	59	57	55	54	53	52	50	50	48	47	46	45	43	42	41	40	39		
83	98	96	94	92	90	88	86	84	83	81	79	77	76	74	72	71	69	68	66	65	63	62	60	59	58	56	55	53	52	51	50	49	47	46	45	44	43	42	40	39		
84	98	96	94	92	90	88	86	85	83	81	79	77	76	74	72	71	70	68	66	65	63	62	61	59	58	56	55	54	52	51	50	49	48	46	45	44	43	42	41	40		
85	98	96	94	92	90	88	86	85	83	81	79	78	76	74	73	71	70	68	67	65	64	62	61	59	58	57	55	54	53	52	50	49	48	47	46	44	43	42	41	40		
86	98	96	94	92	90	88	87	85	83	81	80	78	76	75	73	71	70	68	67	65	64	62	61	60	58	57	56	54	53	52	51	50	48	47	46	45	44	42	41	40	39	38
87	98	96	94	92	90	88	87	85	83	82	80	78	76	75	73	72	70	69	67	65	64	63	61	60	59	57	56	55	53	52	51	50	48	47	46	45	44	43	42	41	40	39
88	98	96	94	92	90	89	87	85	83	82	80	78	77	75	74	72	70	69	67	66	64	63	61	60	59	57	56	55	54	52	51	50	49	48	47	45	44	43	42	41	40	39
98	98	96	94	92	90	89	87	85	83	82	80	78	77	75	74	72	71	69	67	66	65	63	62	60	59	58	56	55	54	53	51	50	49	48	47	46	45	43	42	42	40	39
90	98	96	94	92	91	89	87	85	83	82	80	78	77	75	74	72	71	69	68	66	65	63	62	61	59	58	57	55	54	53	52	51	49	48	47	46	45	44	43	42	41	40

F



(Courtesy of Forest Products Research Laboratory

FIG. 22. Relative humidity nomogram.

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straight edge, preferably of transparent material like celluloid, and lay it across so that it cuts the two temperature readings on the two appropriate outer scales. The humidity can then be read off the centre scale at the point of intersection.

An instrument which performs this operation mechanically and enables the humidity as well as the temperature to be indicated or recorded directly at a point outside the kiln has been developed by the author and is shown in Fig. 23.

Automatic Control of Temperature and Humidity.

Instruments which control both the temperature and the humidity of the air in a kiln are available and are perfectly satisfactory, though naturally considerably more expensive than instruments which merely indicate or record.

Automatic control is effected by having the dry-bulb thermometer system connected, through a relay to provide the necessary power, to the steam-valve controlling the amount of steam entering the heating pipes. Similarly the wet-bulb thermometer system regulates the amount of steam admitted to the kiln in the humidifying jets.

It is very debatable as to when and where automatic control ceases to be a luxury and becomes an economic necessity. Certainly automatic control pays for itself when such a large battery of kilns exists as to make it impossible for one man to operate than on hand control. Such a situation is, however, not likely to arise in this country, and the decision whether or not to install automatic control will probably turn on the saving of the kiln operator's time whereby he may be partially released for other jobs.

Where no experienced operator is on duty at night, and the kiln is left in charge of a stoker or night watchman, automatic control commends itself very strongly.

An example of a recording and controlling hygrometer is shown in Fig. 24.

A two-pen recording hygrometer of the non-controlling type is shown in Fig. 25.

A recording hygrometer is by no means the luxury that a controlling instrument often represents. Its presence enables the operator to glance at the chart, make an adjustment to the steam-valves if required, and come back later to see at once the effect of this adjustment. If the instrument is indicating only,

the operator will have to read and write down or memorize the two temperatures, and later compare them with the new readings. The slope of the lines on the chart of a recording instrument obviates the necessity of actually noting the exact temperatures when making an adjustment.

A permanent record represented by the chart of a recording thermometer has its value for the purpose of comparing one kiln run with another, and, moreover, the operation of the kiln at night or, indeed at any other time, can be checked by anyone in authority by reference to the chart. If there are any reasons to doubt the integrity of the operator the case of the instrument should be padlocked, as unscrupulous operators have been known to remove the chart during the night and 'spin' it in the morning before the boss comes in.

Apart from moisture content determination apparatus and instruments for observing the temperature and humidity, the only other apparatus ordinarily required consists of a balance to weigh the relatively heavy kiln samples (the planks or other sizes built into the stack and arranged so they can be withdrawn (see page 27)), and some means of testing the air circulation.

As almost any balance operating between about 20 and 200 lb. is suitable for weighing kiln samples, there should be no need to deal with the matter further here.

Probably the most satisfactory method of **testing the air circulation** is with the aid of an apparatus for producing artificial smoke.

The smoke apparatus cannot be purchased, but it can be made up easily by mounting three large-mouthed bottles in a wooden stand. Each bottle should be provided with a cork drilled to take two short lengths of glass tubing. The middle bottle is connected to the two other bottles by rubber tubing, and the two remaining glass tubes are attached to two long pieces of rubber tubing (about 3 feet long). The first bottle is left empty, the second bottle is filled with concentrated hydrochloric acid and the third bottle is filled with concentrated ammonia. The glass tube in the second bottle should extend deep into the acid, while the other tube should be clear of the acid. Similarly, the glass tube in the third bottle connected to the second should extend deeper into the bottle than the other tube.

Equipped with this apparatus the kiln operator, wishing to test the air circulation, should enter the kiln, and place the end of the rubber tubing connected to the empty bottle in his mouth. When he blows down the tube, dense white smoke (ammonium-chloride) will emerge from the end of the tubing connected to the third bottle. To test the circulation he should direct this tube to various parts of the kiln ducting, the gaps between the timber, &c., and watch where the smoke is carried. Some further remarks on air-circulation testing are given later. Ammonium-chloride being a very light gas is very suitable for this purpose as it is easily carried with the air. It is also quite cool when it emerges and so does not tend to rise as would be the case with smoke generated from burning material.

Kiln Operation

Having now described the schedules of temperature and humidity applicable to kiln-drying, and the instruments required for controlling a kiln, together with the apparatus for testing the rate of drying of the timber, we can proceed to discuss methods of operation.

The normal method of operating a kiln, as the schedules given imply, is to gradually raise the temperature and lower the humidity of the circulating air as the moisture content of the timber falls. Many variations have been proposed at one time or another, but in the author's experience the normal method is the most suitable for all common timbers. It may, of course, be necessary to depart from the normal treatment temporarily for steaming to kill moulds, or if the kiln can be operated during the day only, special treatment is necessary.

If this last is practised, it is usually quite safe to turn off all heat and steam-spray at the end of the day, and to open the air-vents to prevent the humidity building up too much during the night. In the morning the air-vents can be closed and the kiln quickly re-heated at the humidity appropriate at the time.

Intermittent operation of this kind is quite satisfactory and by no means all the time the heat is off is lost time. No drying takes place at night, but the moisture in the timber continues to move towards the surfaces from which it can be readily evaporated next morning.

If the kiln is closed down for, say, fourteen hours each night, the drying time will probably be only about a third longer than with continuous running. The kiln requires more attention, however, as it is not safe to open up the valves when warming and assume that the humidity will keep about right.

It may be helpful to run through the series of operations to be performed in drying a typical load, say, 1 inch thick oak flooring strips.

First the kiln pile is erected, a number of sample boards are tested for moisture content and are built into the pile, after weighing, in such a manner that they can be withdrawn easily. The kiln doors are then closed and steam is turned on.

Let us suppose that the highest moisture test gave a moisture content of 31 per cent. As the timber is oak, Schedule C would be suitable and it would be picked up at the 35 per cent. moisture-content phase. The kiln would therefore be warmed up to a temperature of 110° F. (43·3° C.) at a humidity of 70 per cent.

No precise control of the humidity would be required until the temperature began to approach the top mark. The operator would merely turn on a little steam-spray and as the dry-bulb temperature approached 110° F. he would begin to get the wet-bulb reading about 9° to 10° F. lower than the dry. Finally, he would make the necessary adjustments to bring the wet-bulb temperature to 100° F. (37·9° C.). The conditions would then be left steady till, say, a day or two later, when the kiln samples might have dried to a moisture content of below 30 per cent. More heat would then be turned on to raise the temperature to 115° F. (46·1° C.), and the wet bulb could be brought to 103° F. (39·5° C.) by adjusting the amount of steam-spray. This latter adjustment might be facilitated by exhausting some spent air and admitting a little fresh air. Once the correct setting is obtained the air dampers should be closed as much as possible or heat will be wasted.

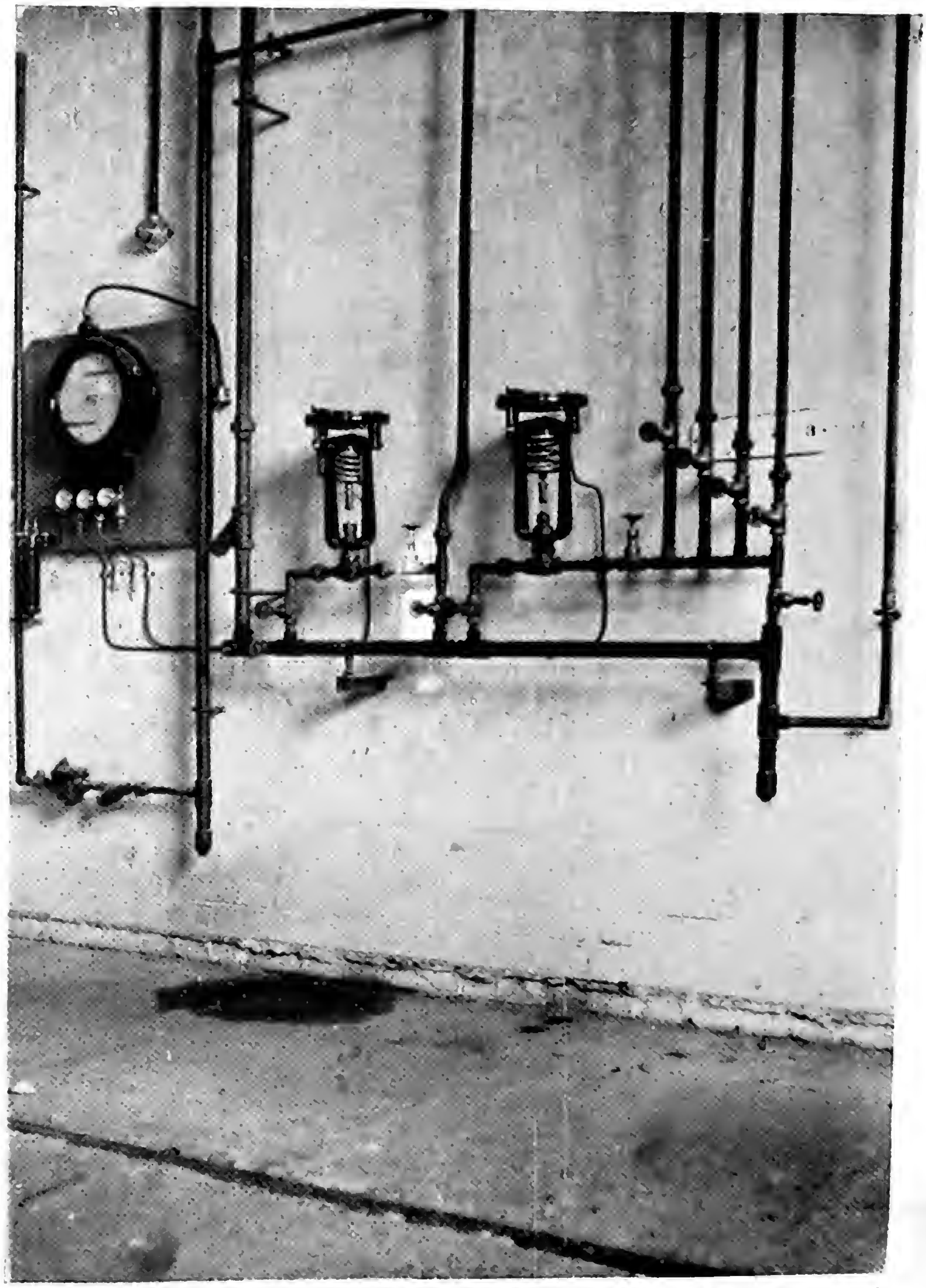
And so as daily weighings of the samples indicate, the temperature is raised and the humidity lowered until any one of the samples is found to have an estimated moisture content of 12 per cent. At this stage it is advisable to re-test all the samples for moisture content—testing also for the distribution of moisture—and for the presence of casehardening stresses, using the prong test described on page 13. While waiting for the mois-

(Courtesy of Forest Products Research Laboratory and of Negretti & Zambra.

FIG. 23. Instrument recording humidity directly operating on the dry- and wet-bulb principle.

The inner pen records the relative humidity, the outer the dry-bulb temperature

(*Crown copyright reserved*)



(Courtesy of Negretti & Zambra and
The Thermal Engineering Co. Ltd.

FIG. 24. Automatic control of a kiln.

The controlling and recording hygrometer on the left operates the steam valves by compressed air. The left-hand automatic valve is controlled by the wet-bulb thermometer and operates the steam spray. The right-hand automatic valve controlled by the dry-bulb thermometer operates the steam-heating coils.

ture test-pieces to dry out in the oven—assuming the oven method is used—the kiln condition should be adjusted to give an equilibrium moisture content of, say, 10 per cent. These conditions are found from the chart on page 95 and prove to be: Temperature: (unchanged) 140° F. (60° C.); Humidity: 65 per cent.

The kiln is run at these new conditions until all samples have dried to about 12 per cent. moisture content or lower. The kiln can then be cooled off, keeping the humidity at about 65 per cent. When the temperature has fallen to about 100° F., the doors can be opened and the timber withdrawn or unloaded. To satisfy himself, the kiln operator should once again make moisture and casehardening tests on his sample boards. It will almost certainly be found that the moisture is fairly uniformly distributed, and that drying stresses are practically non-existent.

Kiln Sterilisation of Lyctus-infested Timber.

Before leaving the subject of kiln operation it may be worth while to refer to the use of a kiln in sterilising timber that has become infested by the *Lyctus* powder post beetle.

Just as the kiln can be used for killing moulds and other fungi so it can be used to kill the eggs and larvae of the destructive powder post beetle. Of course any drying treatment in a kiln would automatically sterilise the timber, but it often happens that timber which is not to be kiln-dried or has already been kiln-dried is attacked by the *Lyctus* beetle.

Such timber should be loaded into a kiln, which should be warmed up in the normal way to a temperature of 130° F. (54.4° C.) and a humidity which will depend on the moisture content of the timber, and can be found from the chart on p. 95.

The idea is to apply conditions such that the timber will be neither wetted nor dried and so will not be stressed in any way. Thus if the moisture content of the timber were 15% the correct humidity to apply would be 80 to 85%.

The duration of the treatment will depend on the humidity selected and the thickness of the timber. At 130° F. and 80% humidity one-inch timber would require 2½ hours treatment, two-inch timber would require 4 hours and three-inch 6½ hours. At lower temperatures and humidity longer times are required.

CHAPTER V

THE CONSTRUCTION AND OPERATION OF A SIMPLE BUT EFFICIENT DRYING KILN

DIMENSIONS—CONSTRUCTION OF THE BUILDING—DOORS—AIR CIRCULATION—FANS—SHAFTING, BEARINGS AND MOTIVE POWER—AIR BAFFLING ARRANGEMENTS—HEATING AND HUMIDIFICATION—STEAM CONSUMPTION—LOADING AND OPERATING—TESTING THE AIR CIRCULATION.

THERE are several kiln manufacturers in this country capable of erecting reliable and efficient kilns and these should be patronized whenever circumstances permit.

However, a manufacturer, mill-owner or merchant may have engineers on his staff and may feel inclined to erect his own kiln. It is to such men that this chapter is addressed.

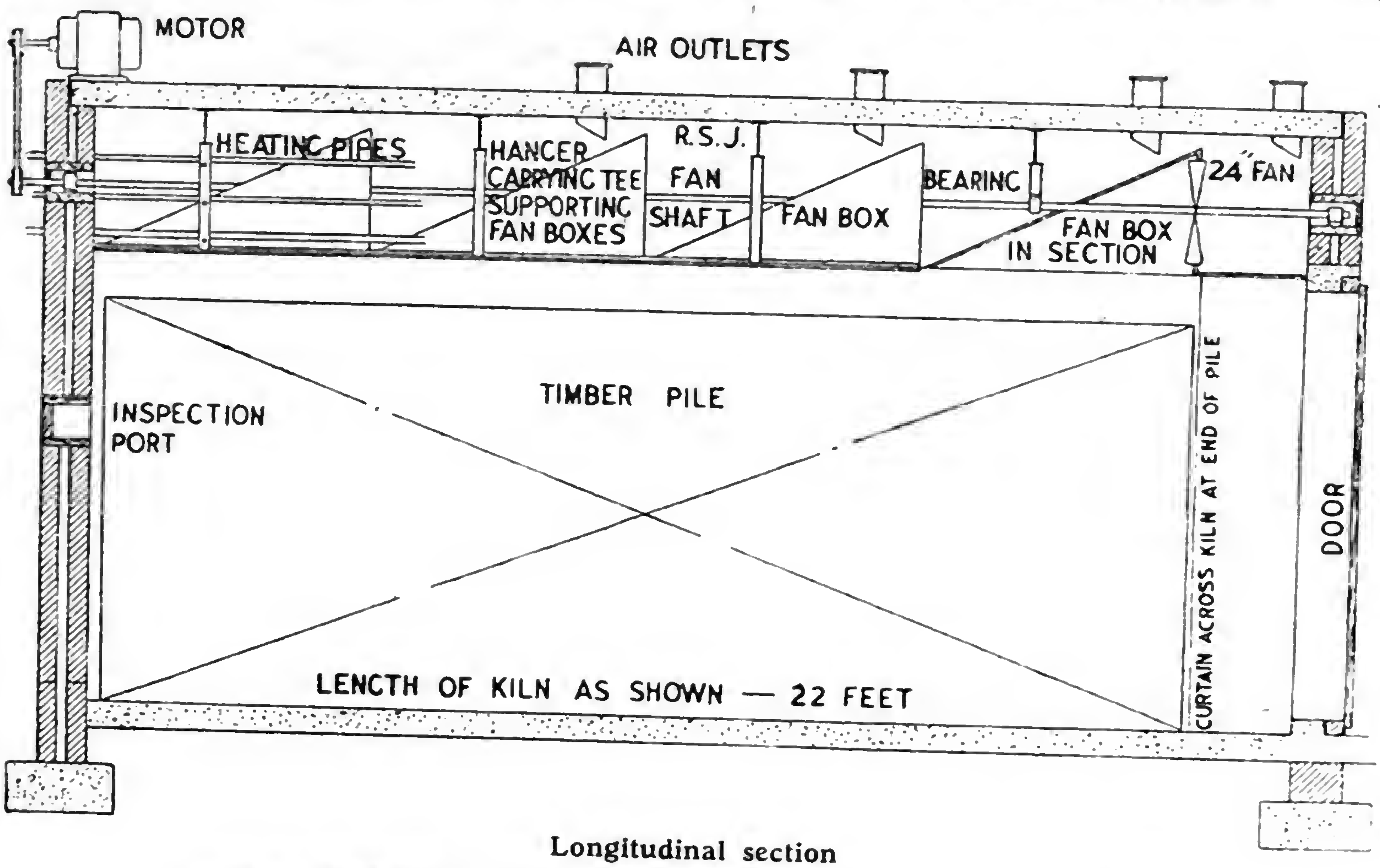
The kiln* to be described below is illustrated in Fig. 26. It can be called an overhead internal-fan kiln because all the gear is situated on top of the kiln, and the fans for circulating the air are within the kiln chamber.

The kiln is relatively cheap to construct and to run, and represents one of the most efficient types available.

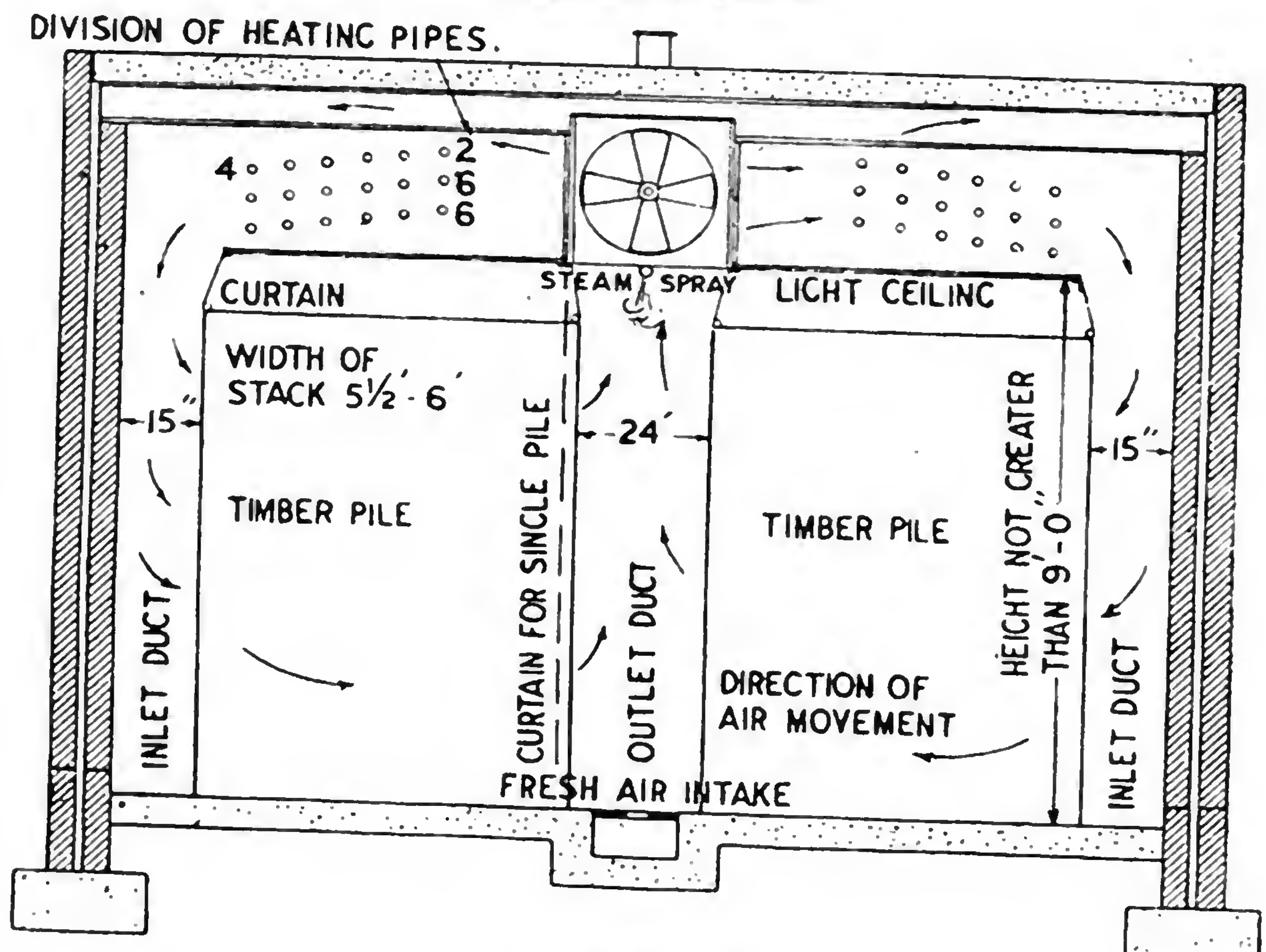
During the war many people have found the single stack type of kiln more convenient for dealing with the odd job lots of timber that the emergency called for. There was also a tendency to favour a long kiln of say 30ft. as opposed to 22ft. as in the example here. But these special conditions will pass and the author has therefore retained the more economical double-stack kiln for the purposes of illustration.

Dimensions. The width and the height of the kiln are fixed, and should be adhered to within a few inches either way. The overall inside width is 15 to 16½ feet, and the overall inside height about 12 feet. The length can be varied to suit the output required, but a fan will be needed for about every 5 feet of kiln length. It is doubtful whether it would be wise to construct a kiln over about 50 feet in length.

* The design was developed at The Forest Product Research Laboratory and the author is indebted to the Director for permission to describe it here. The reader is also referred to Leaflet No. 10 issued free by the Laboratory, and should he prefer a single-stack kiln he should obtain Leaflet No. 18 from the Laboratory.



Longitudinal section



Cross-section

(Courtesy of Forest Products Research Laboratory

FIG. 26. Overhead internal-fan kiln.

(*Crown copyright reserved*)

Let us consider a kiln of the length shown in the figure, viz. 22 feet. Such a kiln will accommodate about 700 cubic feet of square-edged 1 inch thick boards 18 feet long, or about 1,000 cubic feet of 2 inch thick square-edged planks of the same length. In both cases it is assumed that piling-sticks 1 inch thick are employed.

The Construction of the Building

This is preferably carried out in brick and concrete. The walls should be 11 inch cavity brick, provided with proper footings and dampcourse. The cavities should be well ventilated. The floor should be of concrete graded to a point at one end so that it will drain properly. For the roof, reinforced concrete is preferable. When erecting the roof, provision should be made for hanging the piping and shafting, and the light internal baffles. Holes should also be left for the exhaust air-vents.

As the expansion of the roof may be considerable when the kiln is heated to high temperatures, it is advisable to support it on slates or dampcourse material laid on the top of the inner brick walls. Gaps should be left between the outer walls and the edges of the roof so that expansion can take place by sliding over the cavity space.

Composition mortar should be used with the brickwork, and finally the entire inside of the kiln—except possibly the floor—should be painted with a good grade of bituminous paint.

If the kiln is erected in the open the roof will have to be asphalted and drained, or alternatively a light timber roof, covered with roofing felt, can be built over the top of the kiln.

Doors. As even the best doors leak and are a source of heat-loss, it is advisable to brick up one end of the kiln, leaving only a small inspection doorway.

The main doors at the loading end can be constructed of sheet steel riveted to a light strip-steel frame. The doors should be larger than the opening and should close on to a felt strip fixed to the kiln-face. The metalwork of the doors should be well painted with a good brand of aluminium paint, the outsides can be insulated by fixing a light wooden frame to the metalwork, plywood sheets can then be fixed to the timber framing, leaving an air-space of about 1 inch between the sheet metal and the plywood. If desired, some form of insulating material can be fitted into this space. It will be noted that with this construction a door is very flexible as it has no rigid frame. This is an excellent feature because it is desired to pull the door hard against the felt strip on the kiln-face at all points. A rigid door might become distorted and be difficult to pull up. In order to leave the door relatively free, the method of hanging it is im-

(Courtesy of Negretti & Zambra)

FIG. 25. Recording wet- and dry-bulb hygrometer.

portant. The best course is to use long hinges secured to the middle of the door only. Obviously, hinges of this kind must be of very strong construction and they must be well secured to the face of the kiln building.

The door is closed by swinging it into position and pulling it up against the kiln-face by a number of clamps.

With a kiln 15 to 16 feet wide two doors will be preferable to one large door, and a central post can serve to hold the doors in place. A post of this nature will not interfere with loading the kiln.

If two doors are used eight clamps will be required for each door, three on each side and two at top and bottom. If wedge-shaped pieces are fixed to the outside of the door, flat metal bars pivoted on bolts let into the wall can be used to pull the door into position. The felt strip should be coated with tallow to prevent it sticking to the door and tearing away.

Air Circulation

The air in the kiln is circulated by the four 24 inch diameter propeller fans mounted on a shaft running down the centre of the kiln. The air is sucked up the central flue between the two stacks of timber and is deflected into the fans by the sloping baffles. After leaving the fans it travels to both sides of the kiln, passing through the heating pipes. On reaching the walls it travels downwards and enters the stacks between the layers of timber. After passing through the timber it is re-circulated. Fresh air is introduced at floor level by a 6 inch cast-iron water-pipe or a duct in the floor, which is provided with ports at intervals and which communicates with the outside at both ends of the kiln. The exposed ends are provided with flaps to regulate the amount of air entering. Air is exhausted through short lengths of pipe passing through the roof near each fan. Each exhaust pipe is provided with a damper of some sort.

Fans

Any fan-maker of repute will supply a suitable fan if the quantity of air to be delivered is stated. The quantity can be calculated in this fashion: Supposing it is proposed to accommodate two stacks of timber of overall dimensions 18 feet long by 15 feet 6 inches wide by 8 feet high. If the thinnest material

likely to be dried is 1 inch boards, then (with 1-inch thick piling-sticks) the air-space on the face of each pile is $18 \times \frac{8}{2}$ square feet, or for both faces 144 square feet.

Now it is known that the optimum air-speed through the timber pile is about $1\frac{1}{2}$ feet to 2 feet per second. Taking a figure of $1\frac{1}{2}$, the quantity of air passing through the piles will be $144 \times 1\frac{1}{2} = 216$ cubic feet per second. Allowing for friction losses, &c., this amount should be doubled, and as a kiln accommodating this length of timber pile would require four fans, each fan must deliver approximately 108 cubic feet of air per second. Given this information, the fan-maker will manufacture a fan which will do this work at a speed he will state.

Shafting, Bearings and Motive Power

The fan manufacturer will also require to know the diameter of the shafting. For a kiln about 20 feet in length this should be $1\frac{1}{2}$ inches, and for kilns between 20 and 30 feet in length the diameter should be $1\frac{3}{4}$ inches. From 30 to 50 feet, a 2 inch shaft will be needed.

The bearings to take the shaft should be self-aligning, totally enclosed ball-bearings. Hangers to suit the bearings will be supplied by the bearing manufacturer. The hangers must be secured to the kiln roof, and of course proper precautions must be taken in lining up the shaft.

Expansion of the shaft must be provided for by locking it to the bearing nearest to the middle of the kiln only and allowing it to slide in the other bearings. When ordering the bearings, the fact that one locking type is required should be stated. The bearing manufacturer should also be informed of the fan-speed and the power required to drive the fans. The fan manufacturer will state what power is absorbed, but it can be taken as being roughly about $\frac{1}{2}$ horse-power per fan.

The bearings should be lubricated with a good quality high melting-point grease, and extensions should be provided so that they can be lubricated from outside while the kiln is hot. Any grease-gun manufacturer can provide the necessary extensions for a few shillings.

If electric power is available, undoubtedly the most satisfactory drive is by means of an electric motor and 'vee' belts. The

fan manufacturer having supplied the fan-speed and the power required, a suitable motor can be obtained. As the air is being delivered against the natural tendency of hot air to rise, more than one fan-speed may be required. Though the fan manufacturer may quote speed and power for ordinary atmospheric temperatures, the power required at considerably higher temperatures will be roughly the same, but the maximum speed may be nearly double. If only alternating current is available, three sets of pulleys should be obtained so as to give the speed recommended by the fan manufacturers, half as fast again, and twice as fast. An induction motor should be purchased for choice. If a direct current supply is obtainable a variable-speed motor can be bought, and only one set of pulleys is then required. The motor can be mounted on the kiln roof with the pulley end extending over the edge of the kiln and driving the pulley on the shaft below.

If no electric power is available fans will have to be driven by steam engine, turbine, gas engine or from existing line shafting.

Air-Baffling Arrangements

The air-baffling arrangements are relatively simple. They can be constructed of timber or sheet metal. As will be seen in the diagram, sloping baffles are required extending from the bottom of the fan-trunk to the kiln roof. The slope of these baffles should be roughly that shown in the diagram. Triangular sides should be fitted to the sloping baffles on the suction side of the fans. When this is done an open triangular space will occur between each pair of baffles on the delivery side of the fans. The air coming from the fans passes through these spaces and enters the heating pipes.

In order to prevent the air from traversing the space above the timber piles in a diagonal direction and so causing a drift to one end of the kiln, it is necessary to fit transverse baffles or deflectors. If joists are run across the kiln below the ceiling to support the bearings and other gear, they will serve as transverse baffles and nothing further will be required at this point. Finally, false ceilings extending from the base of the fan-trunk to the outside edges of the timber stacks must be provided.

Canvas baffles let down to the top of the timber stacks prevent the air from short-circuiting over the top.

Heating and Humidification

The steam-heating pipes are mounted above the timber stacks on either side of the fan-trunk. Ordinary 1 inch seamless pipe can be used, and this should be well cleaned and painted with a good quality heat-resisting aluminium paint. An adequate fall should be provided to ensure proper draining of condensate from the coils. A fall of about ¾ inch per 10 foot run will be found suitable.

The return bend type of heating coil is very suitable, and if arranged on an incline there should be ample space for all the pipes required.

The coils should be divided into, say, three separate units so that for low-temperature work only one-third of the pipes are used, additional banks of pipes being turned on as higher temperatures are required. In conjunction with a pressure-reducing valve on the main steam supply pipe this arrangement makes for very flexible control, and largely obviates the trouble experienced with banking up of condensate when a large coil is operating with very little steam entering.

Each bank of pipes should have a separate return pipe, each fitted with a check-valve and leading to a common collecting-pot mounted several feet below the points of emergence from the heating coils. The pot should be connected to a steam-trap which can return the condensate to the boiler. If this is done the danger of steam blowing back from one coil into another is practically cut out.

Assuming brick and concrete construction is used and that the kiln is not unduly exposed, the area of heating surface required will be roughly 1 square foot per 10 cubic feet of kiln-chamber (i.e. the space available for timber). Thus if 1 inch pipe is used in a kiln 22 feet long, about 38 pipes will be required, the steam-spray pipe counts as one, leaving, say, 18 on each side. With this number of pipes it will be possible to obtain the maximum temperatures ever required, that is in the neighbourhood of 100° C. (212° F.).

The steam required for humidifying the air is introduced by a 1 inch pipe running along the kiln below the fan-duct. ⅛ inch holes drilled in the bottom of the pipe serve to spray the steam into the air as it enters the fans. As the spray-pipe lies above

the space between the timber stacks, it is of no consequence if water as well as steam is sometimes blown out. Therefore no special precautions are required for draining the spray-pipe.

Steam Consumption

A kiln of the size shown will not normally consume more than 200 lbs. of steam per hour, but if rapid warming up is required or it is desired to maintain saturated conditions at a temperature of about 212° F. for steaming or reconditioning purposes, a much higher consumption (up to 1,000 lbs. per hour) must be allowed for.

Loading and Operating the Kiln

Having briefly described the construction of the kiln, we can go on to consider the method of operating. In what follows below certain additional details of construction will emerge.

Loading the Timber into the Kiln. In general the remarks regarding stacking timber for air-seasoning in Chapter III apply also to kiln-drying. In kiln-seasoning, however, there is no need to vary the thickness of piling sticks to control the rate of drying. The thinner the sticks employed, the more timber can be loaded into the kiln, but it must be remembered that too small a space between the rows will impede the passage of air, and also very thin sticks offer little mechanical support to the stack. At the higher temperatures employed in kiln-drying as opposed to air-drying, the timber becomes fairly plastic and much natural tendency to warp can be restrained by the weight of the timber above. The process is analogous to 'steam' bending where the timber is softened by heating so that it can be bent to any desired shape. In this case the timber may be said to be bent straight by the pressure applied through the piling-sticks. It is a common experience to find timber in the base of a kiln-pile considerably less distorted than that towards the top of the pile. If the sticks are not sufficiently strong they will yield to the timber piled on them. The need for really dry sticks is also obvious, for a stick which itself warps and shrinks, far from helping to restrain warping, will actually encourage it.

The author recalls an occasion when some beech 2 inch furniture squares were being kiln-dried. The timber was self-crossed; that is, some of the squares were used in place of piling-sticks.

The timber on the air-inlet side of the kiln dried considerably faster than that on the air-outlet side, including the 'sticks'; with the result that shrinkage set in earlier on the inlet side and the whole pile toppled over into the inlet duct. Self-crossing, therefore, while permissible in certain cases in air-drying, cannot be recommended unreservedly in kiln-drying. If occasional dry sticks running right across the pile are used in conjunction with self-crossing they will probably prevent the stack from falling over, but considerable warping is inevitable.

Bearing these points in mind, one may say that piling-sticks for use in kiln-drying should not be less than ¾ inch square,and sticks 1 inch in section are a fair compromise for most purposes. It should also be remembered that sample pieces should always be built into the stack, and these are made withdrawable by notching the sticks above. Sticks less than ¾ inch thick would be so weakened by notching that they would be unable to support the timber above. If thicker sticks are used for the rows containing sample pieces than for the rest of the stack, drying will be more rapid at these points and so the behaviour of the sample pieces will not be representative of the load as a whole.

There is one point which must be particularly observed in piling timber into a kiln which is of less importance in air-seasoning: The edge or face of the stack at which the air enters should be kept as straight as possible. If certain boards or planks project the air will be deflected, with the result that the rows immediately above the projecting piece (in the case of a kiln in which the air is delivered from above) will receive more than their fair share of air, while those immediately below will be partially starved.

In air-seasoning it is always necessary to leave a gap between adjacent boards or planks, but in a forced-draught kiln it is advantageous to pile closely edge to edge, as it is desirable that the air should travel horizontally and any tendency for vertical air movements within the pile should be discouraged.

Canvas baffles should be used to prevent the air from passing round the pile. In the case of a double-stack pile as used in this particular kiln, canvas baffles should be extended from the edges of the false roofs to the tops of the stacks, and at each end of each duct canvas curtains should be hung to prevent any air from short-circuiting round the ends of the stacks.

In the kiln now being considered, and indeed in any kiln of the types hitherto described, the stacks should not be built right from the floor to close against the ceiling.

In an overhead-type kiln the descending inlet air tends to overshoot the space immediately below the false ceiling, and difficulty is often experienced in persuading it to pass along the floor. In a basement-type kiln the reverse applies. Moreover, the ceiling and the floor are often cooler than the kiln as a whole and condensation will then occur in these areas.

The timber piles should be lifted clear of the floor, either on wooden baulks about 6 inches high or on loading bogies. Piling should be discontinued when within about 9 inches of the ceiling.

In the kiln dealt with in this chapter the full length of the kiln cannot be utilized for piling timber. Referring to the diagram, it will be seen that the area adjacent to the loading door is not within that dealt with by the fans. A kiln of this type 22 feet long will not, therefore, accommodate timber over 20 feet in length. Obviously, for practical reasons, some few inches must be left between the ends of the stacks and the door. There is, however, absolutely no necessity to load the kiln up to capacity. Provided suitable canvas baffles are arranged, the smallness of the load is of no consequence. Moreover, by dropping a canvas curtain down the length of the kiln from one side of the fan-trunk to the floor, the kiln can be operated as a single-stack one.

The width of each stack—in the direction of the air movement—should not exceed 6 feet.

The timber loaded in and the doors closed, the kiln can be warmed up and operated on the lines indicated at the conclusion of the last chapter.

In kiln operation, as in many other things, experience is the best teacher, but provided enough attention is paid, not even a tyro should fail to manage sufficiently well to avoid damaging the timber unduly. It is, of course, assumed here that the proper schedule and sample pieces would be employed.

The wet- and dry-bulb control hygrometer should be rigged up in the air-inlet duct (in the case of a double-stack kiln of the type described here in one of the inlet ducts) in the middle of the length and height of the kiln. This will be a fairly representative

position at which to study the state of the air as it enters the timber. If, for any reason, it is known that some point exists where the air is particularly hot and dry, the thermometer bulb should be located there. It will be necessary to ensure that the wet bulb receives an adequate supply of distilled or rain water, and that the wick remains soft and pliable. If the kiln is to be operated at high temperatures, it will not be possible to replenish the water supply to the wet bulb by entering the kiln. It is therefore a good plan to have a small supply vessel attached to the instrument and a length of copper tubing leading from this vessel to outside the kiln. A copper funnel soldered to the external end of the tube renders re-filling a simple matter.

If the simple type of mercury-in-glass thermometer, wet- and dry-bulb hygrometer is used, an inspection port is required in one of the kiln walls through which the thermometers can be viewed. With the aid of a cheap pair of binoculars and a focusing electric torch, no difficulty should be experienced in reading the thermometers, particularly if these are of the insulated type having bold figures and a broad mercury column.

The operator will then control the kiln, watching the hygrometer readings. If the dry-bulb thermometer reads too high, he must turn down the supply of steam to the heating coils, and if the wet bulb is too high, he must turn off some of the steam-spray. If the humidity still remains too high it may be necessary to introduce fresh air by opening the dampers on the ends of the fresh-air duct. At the same time it will be necessary to expel some air from the kiln by opening the exhaust air-vents a little. This operation will probably have the effect of lowering the dry-bulb temperature so that more steam will require admitting to the heating coils. When the correct conditions have been attained it will probably be found possible to close the air-vents again, and turn down the supply of heat.

In order to economize steam, every effort should be made to operate the kiln with the air-vents closed, using them temporarily only to secure the right conditions quickly.

Testing the Air Circulation

Using the smoke apparatus described on page 74, the air circulation can be tested. The kiln should be loaded with timber and slightly warmed. Equipped with the smoke apparatus, the

operator should enter the kiln and have the doors closed after him. He can then blow smoke at various points and observe where it travels. If he tests on the air-inlet side of the stack, smoke should be drawn in between each layer of timber at all points in the height and the length.

If the circulation is found to be unsatisfactory at some points it may be possible to improve matters by altering the fan-speed or by introducing canvas or plywood baffles in such a manner as to deflect air to the starved parts. Trial and error methods are the best guide as to where such baffles should be located, and it is obviously quite impossible to consider the matter in detail here. In the design of kiln just described the air circulation should be sufficiently uniform, and no auxiliary baffles should be required if the instructions given have been followed.

Anyone contemplating constructing his own kiln, whether of this type or any other, is strongly advised to consult the Forest Products Research Laboratory at Princes Risborough, Aylesbury, Bucks.

CHAPTER VI

TIMBER DRYING AND THE 'SMALL MAN'

USE OF THE WARM STORE TO DRY OFF AIR-SEASONED TIMBER—TEMPERATURES TO BE EMPLOYED—GAUGING THE RATE OF DRYING—CONSTRUCTION OF A SIMPLE STORE.

THERE are thousands of small operators in this country who do not handle timber in sufficient quantities to justify the installation of a drying kiln, but who require timber sufficiently seasoned for high-class interior woodwork. As there are not many merchants who supply kiln-dried timber at a price sufficiently attractive to the 'small man', he is obliged to purchase air-seasoned material and complete the drying process himself.

This finishing-off process can be accomplished in any warm situation provided speed in drying is of no great consequence.

Air-dried timber has an approximate moisture content of 20 per cent., while for most interior uses a moisture content of about 12 per cent. is desirable. As explained in a previous chapter, shrinkage begins in earnest at a moisture content of about 30 per cent. so that roughly half the total shrinkage that is going to occur in a piece of timber destined for indoor use has already occurred in air-drying, the other half occurring either *in situ* if no further drying is given before manufacturing and installing, or in a kiln or warm store if that eminently desirable process is adopted.

The use of a warm situation for finishing off has been known for generations, and it is still quite common to hear of a builder or small cabinet-maker storing timber in the kitchen to dry it off. Some even go so far as to stack timber over a boiler or other hot situation, but this practice is dangerous. Partly because drying may be too rapid and casehardening and splitting may result, and partly because if left overlong the timber will become too dry, so that swelling will occur when it is put into use.

The ideal warm store should be one in which the humidity of the air is kept approximately constant, so that all timber placed therein would eventually dry to about 10 to 12 per cent. moisture content.

The simplest way of securing roughly constant humidity conditions is to regulate the temperature so that outside atmo-

spheric air is dried sufficiently on heating to secure the desired humidity. Within reasonable limits this is automatically secured if the temperature in a warm store is maintained about 15° F. (8° C.) above the outdoor temperature.

As constant attention would be required to ensure this, a rough compromise will obviously appeal. Such a compromise consists in maintaining a temperature of about 50° to 55° F. in the winter months (October to April) and 80° to 85° F. in the summer months (May to September).

This of course implies the application of some heat even during summer, and therefore renders a living-room unsuitable for the purpose of a timber store if the comfort of the occupants is to be considered.

Many houses, however, contain a little-used room which can be set aside for this purpose. A boiler-room immediately suggests itself, but would probably be unsuitable in winter as the temperature would be too high, whereas it would be perfectly suitable in summer.

Timber stacked in a warm store to dry off should be properly piled with sticks, and if at all possible, the stacks should be weighted with bricks or scrap metal to reduce warping.

It is clearly quite impossible to give any idea of the time required to dry off timber in this primitive manner as so much will depend on the degree of ventilation afforded, the amount of timber relative to the size of the room, &c., quite apart from such considerations as the species and thickness of timber to be dried.

Here, again, the best plan is to weigh a few typical pieces—on the household scales if nothing else is available—and re-weigh at intervals till approximately constant weight is attained.

Some operators who do not feel inclined to go to the length of installing a kiln may at any rate be prepared to construct a special warm store, heating it from an existing hot-water supply.

If it is decided to construct a proper warm store, ordinary domestic radiators should be avoided. Instead, hot pipes should be run backwards and forwards over the floor. The pipes should be kept a few inches off the floor. Immediately above the pipes joists can be run across the room at intervals, and the timber can be piled on these joists, using 1 inch thick piling-sticks and leaving gaps between the pieces in each row. At the bottom of

the room—if possible below the pipes—some form of ventilation should be provided. A few air-bricks set at intervals round the room would serve admirably. Pieces of board can be placed in front of the air-bricks to regulate the amount of air entering.

At the top of the room in the ceiling, or in the walls close to the ceiling, exhaust air-vents should be fitted. These again should be provided with some form of damper. Fresh air will then enter at the bottom of the chamber, will become heated by the pipes and will rise up through the timber and escape at the top.

It is understood that it will be possible to regulate the amount of heat entering the pipes, and that a thermometer will be hung somewhere in the chamber in a position which may be considered represents about the average temperature for the room.

Though his drying will take longer, and he will be unable to handle wet timber without air-seasoning it first, the small man equipped with some form of warm store and operating it intelligently can produce thoroughly seasoned timber, which may be used without fear of shrinkage or warping in the best class of construction.

CHAPTER VII

THE BEHAVIOUR OF SEASONED TIMBER IN USE

TIMBER ALWAYS HYGROSCOPIC—EFFECT OF SEASONAL VARIATIONS IN ATMOSPHERIC CONDITIONS—EQUILIBRIUM MOISTURE CONTENTS—THE MOVEMENT OF TIMBER WITH CHANGING HYGROMETRIC CONDITIONS—MOVEMENT OF SOLID AND LAMINATED WOOD—METHODS OF KEEPING MOVEMENT TO A MINIMUM AND OF REDUCING MOVEMENT—THE BEHAVIOUR OF SEASONED TIMBER IN NEW BUILDINGS—THE MOST SUITABLE MOISTURE CONTENT FOR SPECIFIC PURPOSES—ABSORPTION OF MOISTURE BY DRY TIMBER.

HOWEVER dry it may be, and whatever methods are employed to dry it, timber remains a hygroscopic substance. It is always striving to attain equilibrium with the air surrounding it. If it is moved from a dry situation to a damp one it will absorb moisture and swell, if it is moved back to the dry situation it will lose moisture and shrink.

Most timber articles are not moved about from dry to wet situations and vice versa, but the same effects are produced because the surrounding atmosphere is always changing.

As the process of absorbing or losing moisture is rather slow under ordinary conditions, timber never attains complete equilibrium with the atmosphere because this changes its state from hour to hour. The moisture content of wooden articles also changes from hour to hour in an effort to catch up with the air surrounding it, but unless the article is very small the moisture content variations over a short period are very minute and have little or no effect on the shape of the article.

Exceptions sometimes occur, however, as for instance on a really clammy day when walls stream with moisture. Under such conditions even fairly substantial articles may be sufficiently affected in a few hours for noticeable changes in shape to take place. A hardwood floor which has been laid with the strips or blocks tight together and without provision for expansion may 'come up' on such a day.

Generally speaking, however, day-to-day variations in atmospheric conditions have no visible effects on furniture, panelling, flooring, &c. Such articles are, moreover, usually partially protected by polish, paint, &c., and these coatings retard the ingress and egress of moisture.

During the seasons of the year—although big variations occur from hour to hour—the condition of the air undergoes definite smaller changes which persist for long periods. Thus winter is colder and damper than summer. All but the very largest sizes of wooden members undergo an appreciable change in moisture content with the seasons, and the change is sufficient to cause the timber to swell or shrink enough to have practical effects.

The temperature of the air has small effects on the moisture content of timber, but the air humidity has quite large effects. If a piece of timber is kept in an atmosphere maintained at a temperature of 60° F. and a humidity of 50 per cent., it will eventually attain a moisture content of about 10 per cent. If the temperature is now raised to 100° F. and the humidity unaltered, the moisture content now attained in time will be about 8 per cent. A change of only 2 per cent.

On the other hand, if the temperature is maintained constant at, say, 80° F. and the humidity is first held at 40 per cent., the piece would attain a moisture content of about 9 per cent., and then, if the humidity is altered to 70 per cent., the moisture content would rise to 15 per cent. A change of 6 per cent. for a perfectly normal fluctuation in humidity.

Fig. 27 shows the relationship between the moisture content of most timbers and the surrounding atmospheric conditions. Such a chart is not only useful in determining the correct conditions to apply at the conclusion of kiln-drying, as has been described in an earlier chapter, but also enables one to discover to what moisture content timber should be dried when it is to be used under known conditions of temperature and humidity. All countries record the temperature and humidity of the air and such information is readily obtainable. If a British manufacturer receives an order for wooden articles for foreign countries, he can ascertain the average temperature and humidity prevailing and by reference to the chart decide the moisture content at which manufacture should take place. This, of course, will not hold good if the wooden articles in question are to be used where artificial heat is likely to be applied. But for all tropical or semi-tropical countries the chart will provide the answer.

The chart also enables one to appreciate the effect that air of a certain kind is likely to have on timber seasoned to a certain moisture content. For instance, reference to the chart shows

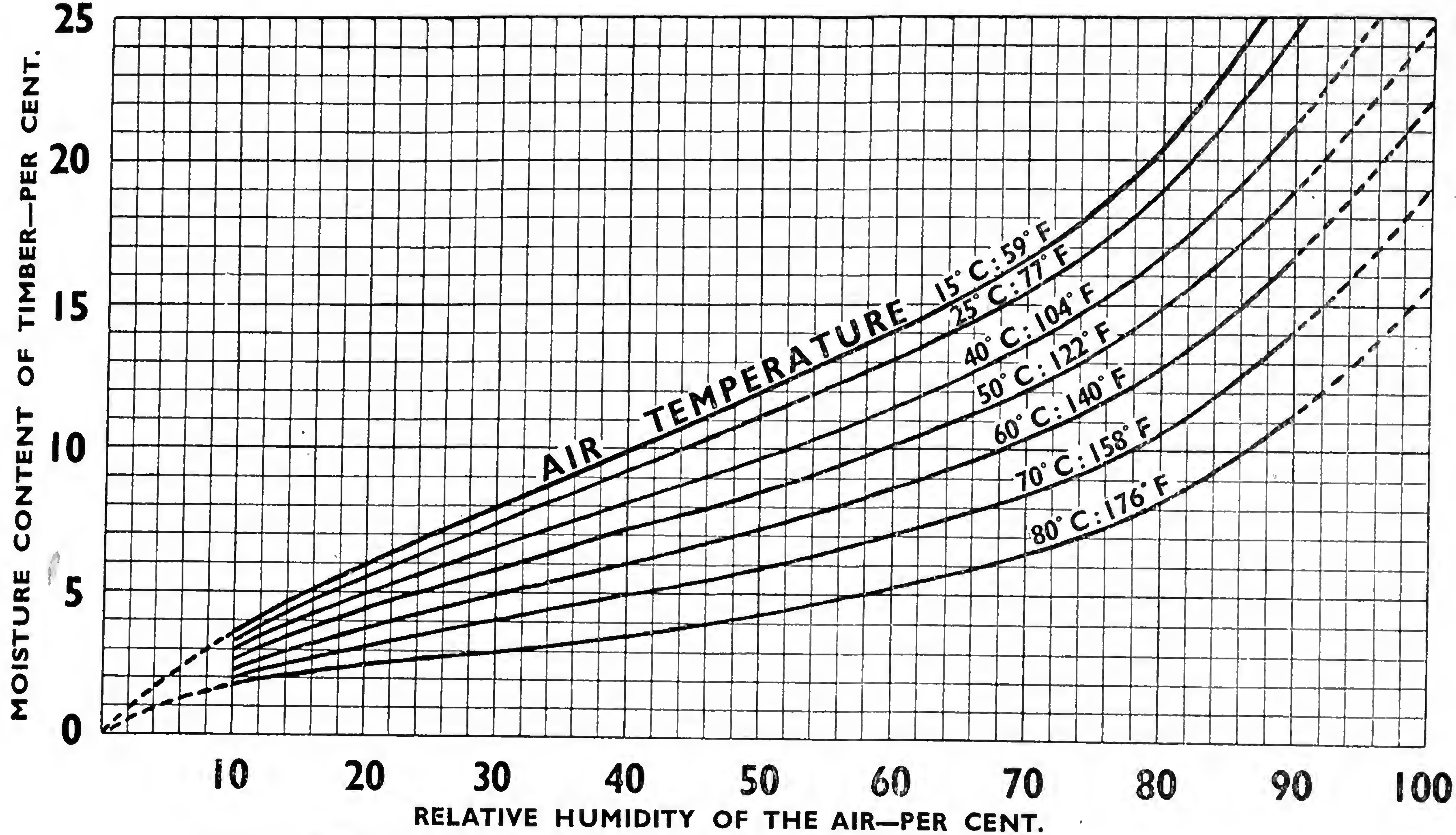


FIG. 27. Relation between moisture content of wood and the surrounding atmospheric conditions.
The curves are approximate only and apply to most timbers.

one that timber air-dried to about 20 per cent. moisture content will tend to dry considerably if exposed to indoor winter air which may have a temperature of 60° to 80° F. and a humidity of 40 to 60 per cent. In other words, it indicates the 'pull' that air conditions may be expected to have on the moisture in timber.

A wooden article kept in an unheated place but protected from sun and rain will approach equilibrium with average summer conditions when they have persisted for as long as possible, i.e. about the middle of September.

Obviously, the average temperature and humidity occurring during an English summer vary from place to place and from year to year, but a temperature of about 65° F. and a humidity of about 65 per cent. would be fairly typical. This would mean that the article in question would tend to attain a moisture content of about 14 per cent. Equilibrium with winter conditions would be most nearly attained towards the end of April or early May, and if we take the average winter temperature as 45° F. and the humidity as 80 per cent., the wooden article would tend to have a moisture content of about 20 per cent.

In the case of an article kept in a place heated in winter about the same moisture content (14 per cent.) would be attained towards the end of summer, since indoor and outdoor conditions are virtually the same during the summer months. But during winter, when the heating is in operation, conditions indoors will be considerably warmer and drier than outside. Even with moderate heating an average temperature of 65° F. would probably be maintained, and the effect of keeping this temperature about 20° above the outdoor temperature would be to lower the humidity by about 40 per cent. Assuming, then, that the indoor humidity averaged about 40 per cent., the article would tend to approach a moisture content of about 10 per cent. towards the close of the heating season.

As a matter of fact to be strictly correct one should point out that the equilibrium moisture content that timber will attain under any given conditions is influenced by its previous state. If it was wetter before, it will come into equilibrium at a higher moisture content than if it was drier and had to absorb moisture. This hysteresis effect is not very large as a rule—1 or 2 per cent. moisture content—but it is there nevertheless, and affects the shrinkage or swelling of timber proportionately.

Taking the above figures as typical, it will be seen that timber kept in an unheated situation will fluctuate about a mean moisture content of 17 per cent., and timber kept in a place heated in winter will fluctuate about a mean moisture content of 12 per cent.

And these fluctuations will go on year after year and century after century without appreciable alteration. Pieces of timber hundreds of years old, taken from old roof timbers, have been found to behave in almost exactly the same way as material which was part of a growing tree a bare few weeks before.

A mere variation in moisture content from season to season would be of no importance were it not accompanied by shrinkage and swelling. As we have seen in an earlier chapter, the shrinkage of timber is different in the different grain directions and therefore often leads to warping. Swelling is merely the reverse of shrinkage and so a piece of timber is just as liable to warp on being re-wetted as on drying. Really it is tending to go back to its original shape, but if it has been worked and machined in the meantime the nett effect will be to cause it to distort.

The movement of seasoned timber when subjected to changing atmospheric conditions is therefore just as likely to take the form of warping as of straightforward changes in dimensions.

The Movement of Timber with Changing Hygrometric Conditions.

As we have seen earlier, shrinkage (and therefore swelling also) is largest in a direction tangential to the annual rings, is smaller in a direction radial to them, and is very small indeed in a longitudinal direction. Therefore in considering movements occurring in seasoned timber in use we must always refer to the grain direction. Movement along the grain, small enough over the whole shrinkage range, is infinitesimal over the range encountered by seasoned wood, so can be disposed of at once.

The movement in the other two grain directions is considerable however.

For all practicable purposes shrinkage may be said to begin at about 25 per cent. moisture content and to be directly in proportion to the drop in moisture content thereafter. We have seen that timber destined for indoor use should be seasoned to

about 12 per cent. moisture content, and that it may be expected to fluctuate by plus or minus 2 per cent. Thus it will be seen that seasoned timber will tend to move about one-third to one-quarter of its total shrinkage every year of its life.

This may come as a bit of a shock to some people, who are quite accustomed to the idea that timber shrinks in drying but regard it as quite stable once dry.

When dealing with the actual movements which occur, it is convenient to consider the change in size experienced by a piece having a width of 1 foot.

A plain-sawn oak board exactly 1 foot wide when green will shrink about half an inch in drying to a moisture content of 12 per cent. When subjected to ordinary living-room conditions it will swell about $\frac{1}{16}$ inch in summer and shrink about $\frac{1}{16}$ inch in winter.

Thus we have the following table of dimensions for the piece:

Width when green	12	inches
Width when seasoned to 12% moisture content	$11\frac{1}{2}$	"
Width at the end of summer (14% moisture content)	$11\frac{9}{16}$	"
Width at the of winter (10% moisture content)	$11\frac{7}{16}$	"

For a quarter-sawn piece of oak the movements are a little over half the above.

Provided the plain-sawn oak board referred to above was so fitted that it was free to move $\frac{1}{16}$ inch in either direction, it would give no trouble in service, though there might be a very slight tendency for it to distort. It will be seen that but for the fact that it was previously seasoned to the *average* moisture content it would attain in service, the movement in one direction would have been greater initially with every probability that it would have given trouble.

An oak board was used above as a typical example, but timbers vary quite a lot in their shrinkage and to a lesser extent in their movements when seasoned. Of all the timbers in common use teak is probably the most stable. This is not entirely accounted for by its relatively small shrinkage, but is in some measure due to its hygroscopic qualities. Whereas most hardwoods fluctuate between moisture contents of 10 and 14 per cent. when kept under ordinary living-room conditions, teak will fluctuate between about 8 and 11 per cent. moisture content, three-quarters of the range of most common hardwoods. Thus, though the total shrinkage and the movement produced

per unit change of moisture content may not be much less than other timbers, the nett movement over a given range of atmospheric conditions is certainly not more than three-quarters of that of other timbers.

The softwoods commonly employed are, generally speaking, more stable than hardwoods as their shrinkage is smaller, but as their hygroscopic characteristics are about the same they are not quite so stable as teak.

We have deliberately cited the behaviour of teak in order to bring out the importance of hygroscopic tendencies as well as shrinkage when considering the stability of seasoned timbers in use.

As a general rule a timber having a small shrinkage in drying may be assumed to be more than usually stable in service, but exceptions may occur as we have seen above.

Apart from one or two exceptions such as teak, the movement of most timbers when subjected to normal atmospheric changes is very similar. One timber may be more stable in general than another, but it is not uncommon to find individual pieces of the more stable species moving more than individual pieces of the less stable wood. Because of the differences which occur within any one species, it is an extremely difficult matter to obtain figures representative of the movement of a timber.

For most practical purposes timber may be reckoned to move 0·02 to 0·03 inch per foot of width for every 1 per cent. change in moisture content. And this approximate figure applies whatever the timber and whatever the grain direction except along the grain, of course.

Leaving aside exceptions like teak and timbers having very twisted or irregular grain, which would cause a pronounced tendency to warp with shrinkage or swelling, it may be said that there is little to choose between most common timbers from the point of view of stability under ordinary atmospheric fluctuations.

Timber can be compressed and stretched a fair amount without rupture, and therefore ordinary movements can often be accommodated by the structure itself even when no provision for movement has been made. Joints too, though apparently tight, can absorb some movement of the timber on either side. For this reason articles manufactured from unsuitably seasoned timber often give no trouble.

When construction involves the use of large widths it would be extremely foolish to use incorrectly seasoned timber or to omit to provide freedom of movement. Thus one finds that panels are held in grooves, table-tops are secured by buttons, and so on.

Minimizing Movement in Wood

This defect of continual movement, of so little importance in some things, but of sufficient a nuisance in most timber work, has led to many attempts at reduction either by methods of construction or by treating the wood in some way. We will deal first with the methods of construction.

As timber moves less in a radial direction than in a direction tangential to the growth-rings, it is expedient to arrange matters so that the grain direction is such that the smallest movement occurs where it is desirable that it should be at a minimum. Often this means that the largest overall dimensions are in the radial direction of the timber grain. For instance, quarter-sawn timber is generally preferred for strip or parquet flooring because it is important to keep the movement across the top of a large expanse like a floor at a minimum. (There are other reasons too, such as the better wearing properties of edge-grain timber.) Were it not for the joints a large floor would move several inches, and even though the joints absorb a large part of the movement, it is always necessary to provide expansion joints round the room, though quarter-sawn timber is used.

The device of building up boards out of layers of timber, arranged so that the movement of one layer is restrained by the practically stable longitudinal grain of adjacent layers, certainly has the effect of reducing movement very considerably. Generally speaking, the movement across the width of a plywood board is about one-tenth of that of solid wood, but the movement in the thickness is, of course, unaffected.

Plywood boards, blockboards, and all forms of laminated construction have small movements in the large dimensions, but are very prone to warp unless suitably braced. Movement is restricted forcibly by the action of one lamina on another, but this very restriction implies the imposition of stresses. The internal stresses thus produced may be compared to those in case-

hardened solid wood. We have seen how easily the balance of stresses may be disturbed in casehardened wood, and in the same way they may be easily disturbed in built-up wood. Great care has to be taken to ensure a balanced construction, and that is often upset by finishing off one face of a laminated board in a different way to the other face. An ornamental veneer may be applied, or at least a coating of paint or polish. If only one face is to be exposed the other side will probably receive no treatment, or at least a different treatment.

Some people take particular pains to ensure that both faces receive the same finishing treatment, but they cannot ensure that they will both receive the same atmospheric conditions simultaneously when the article in question is put into service.

Plywood panels fixed to the walls of a room are subjected to different conditions on their fronts and backs. If damp gets through the walls, high humidity conditions will develop between the walls and the plywood panels.

A laminated door may face indoors one side and outdoors the other.

Reducing movement by constructional devices is therefore not altogether satisfactory, whatever the method employed, whatever the type of glue used, whatever the protective finish applied.

In view of the above it is not surprising that many attempts have been made to reduce the 'working' or movement of solid wood by the application of various substances.

It seems probable that the shrinking and swelling of dry wood is largely caused by the withdrawal and addition of water molecules leaving or entering the minute interstices in the cell walls. As the molecules enter these minute cracks they squeeze into them, thus widening the gaps. Fortunately, a good deal of the movement caused in this way is absorbed by the cells themselves which change shape. Only a portion of this change in shape is communicated to the piece of wood as a whole. The process can perhaps be better understood if one considers an individual cell. A cross-section of a cell is very like the cross-section of a tube; an annular wall surrounding an air-space. If the wall of the tube is made to swell it will swell inwards as well as outwards, so that the increase in the outside diameter of the tube will not be anything like so great as if the tube was plugged with some non-

compressible material which would maintain the bore of the tube constant. It is only the summation of the increase in outside diameter of the cells which affects the overall dimensions of a piece of wood when moisture is added. If it were possible to plug up the cells completely movement would probably be considerably increased.

There are two ways of preventing wood from moving with changing hygrometic conditions: One is to seal up the wood in such a way that water-vapour is excluded, and the other is to substitute for the water molecules some non-hygroscopic substance introduced into the minute interstices in the structure of the cell walls.

If timber is to be sealed to exclude all moisture, it will be necessary to coat it with non-porous materials. These are few and far between and are expensive. Metallic coatings can be applied to wood which are virtually effective seals, but apart from the expense of the operation any mechanical damage to the seal will put an end to its efficacy. Any method of lining the wood cells with a non-porous material would only be partially effective, because moisture could still enter via the spaces between the cells.

As far as the author is aware, all methods which have shown any promise have aimed at introducing substances to the spaces in the cell-wall structure.

Stamm* has developed a method whereby a resin is introduced with the aid of a solvent. The wood is treated with a mixture of phenol and formaldehyde, together with a catalyst dissolved either in water or wood alcohol. Timber is soaked in the solution and when sufficient diffusion has taken place is removed and dried slowly. The wood is then baked at 100° C., which has the effect of causing the phenol and the formaldehyde to react to form a resin which is insoluble in water. This treatment has the effect of reducing the movement by about 70 per cent. The method is very expensive, however,costing about £1 per cubic foot.

The author, working in conjunction with W. G. Campbell, at The Forest Products Research Laboratory, developed another method in which timber was soaked in an aqueous solu-

* Stamm, Alfred J., 'Shrinking and Swelling of Wood Reduced by Synthesing Resins within the Wood', *Modern Plastics*, April, 1937.

tion of sorbitol.† The experiments indicated that it will be possible to reduce the movement by about 50 per cent. at a cost of 12*s*. to 15*s*. per cubic foot.

Obviously, both the above methods can have no general application at present on account of their high cost, but other substances may be discovered which are less costly.

The Behaviour of Seasoned Timber in New Buildings

Most buildings in this country are constructed with the aid of a vast amount of mortar, concrete and plaster. All these substances are mixed with water and applied in a very wet state. Much of the contained water takes some months to dry out unless special efforts are made to expedite the process.

With so much moisture about, it is not surprising that the atmosphere in a new building remains excessively humid for some time after the shell is completed. A good deal of the timber work in a building has to be installed during the construction of the shell, but this is mostly of a rough nature, so that it is of no great consequence if it absorbs moisture and subsequently shrinks. Even though the installation of the high-class interior woodwork is delayed until the last possible moment, there is considerable danger that it will absorb moisture. Let us consider what the effect of such absorption may be.

We have seen that woodwork for interior use should be seasoned to a moisture content of about 12 per cent. If timber so seasoned, is installed in a new building still far from dry it will absorb moisture and swell. The conditions may easily be so damp that it would be quite possible for some of the smaller sections of timber installed to attain a moisture content approaching 20 per cent. Seasoned timber fixed in position and subjected to such damp conditions may do one of two things or a combination of both. It may attempt to swell and be restrained from securing relief either by doing so or by warping, in which case it will become compressed. Or it may succeed in swelling, bursting its restraints, bulging, warping and generally distort-

† Bateson, R. G., 'The Shrinking and Swelling of Wood. Experiments on the Influence of Sorbitol,' *Chem. Trade Jour. and Chem. Eng.*, 11 Dec., 1936.

ing. In the former case some of the compression caused may become permanent, so that when the timber eventually dries out to 12 per cent. moisture content again it will be smaller than when originally installed, and gaps will occur at joints. In the latter case some damage will be permanent, some will disappear as the moisture content of the timber returns to about 12 per cent. In either case some permanent damage will be done and repairs will be advisable, if not an absolute necessity.

That trouble with woodwork in new buildings is by no means universal and can be accounted for by three factors:

(1) Some fair measure of drying out is usually secured.
(2) Timber work installed is very often insufficiently seasoned in the first place.
(3) The public will put up with a lot of minor defects in order to get into a new building.

Some architects and builders see to it that temporary heating is applied for some weeks before any high-class joinery work is fixed in position. This is undoubtedly the proper practice and complete satisfaction can only be assured when this is done. The compromise, usually unwittingly put into operation, of using timber seasoned to a moisture content of, say, about 16 per cent.,probably means that no permanent damage will result from absorption of moisture because it will not be very great, but certainly means that ultimately there will be some open joints and some warping.

It should be clearly understood that there is no suggestion that a new building should be heated excessively with a view to drying it out rapidly. It is not usually very difficult to connect up the heating system temporarily if this is in the form of central heating. In any case, the piping will have to be installed prior to the decorative woodwork and there is no great labour involved in connecting up the radiators even though they may have to be disconnected again later.

Where no central heating system is to be used fires can be lighted and oil stoves can be placed in those rooms not equipped with fireplaces.

If it is known that the decorative timbers have been seasoned to the correct moisture content of about 12 per cent., a simple test enables one to determine when the building is sufficiently dry. Thin sections should be cut from some of the timber as it

is received. The sections should be cut across the grain so that a large proportion of end-grain surface is obtained. Let us assume that an oak parquet floor is to be laid. From several of the oak flooring blocks sections the full width and thickness of the blocks, and about $\frac{3}{8}$ inch along the grain should be cut. Each section should then be weighed as accurately as possible. These sections should then be tied up in bundles, separating the sections from each other by small strips of wood so that the air can pass freely between them. The bundles should be suspended in positions where the floor will be laid. If the floor is to be laid on a sub-floor of concrete, a bundle should be placed on the concrete and covered over with an inverted tin or something similar. After some days the bundles can be untied and the sections reweighed. If they have gone up in weight, further drying of the building is required. The bundles should be left in position and broken up and weighed at intervals until the sections have returned to their original weights. It is then perfectly safe to lay the floors or carry out any work involving the fitting of high-class joinery, &c.

If apparatus for determining the moisture content of timber is available (that is, a fairly sensitive balance and an oven), sections adjacent to those used in the bundles should be tested for moisture content. Assuming these represent the moisture content of the corresponding sections used in the bundle, the variations produced by the atmosphere of the building can be calculated in terms of moisture content. In which case the bundles should be left in position until their weights indicate that they have dried to about 12 per cent. moisture content.

It should be hardly necessary to add that it is of very little use taking the precautions dealt with above if the building is to be shut up and abandoned for some time after completion. If the building is not to be occupied immediately the heating should be kept going—if it is cold or damp weather—even though the measure of heat applied is not sufficient to ensure 'comfort'. If the heat is turned off and the timber work left to its fate until such time as the building may be handed over to tenants, and the weather is cold and damp, it is more than likely that so much moisture will be absorbed that trouble with the timber work will be experienced.

Except where air-conditioning plant is in operation all the

year round, it is inevitable that the moisture content of some of the timber work will approach 14 per cent. towards the end of summer. There is therefore no reason why conditions drier than those of summer need be maintained while a building is awaiting occupation. It will suffice if the air in the building is kept about 10° F. (5° C.) above the outdoor temperature. If the weather is warm and dry there will, of course, be no necessity to apply heat.

The Most Suitable Moisture Content for Specific Purposes

In previous pages many references have been made to equilibrium moisture contents, and it has been demonstrated that a figure of about 12 per cent. is suitable for most timbers destined for indoor use. Similarly for outdoor use (under cover) the equilibrium moisture content is of the order of 17 per cent.

There are, however, many applications in which timber is sometimes outdoors and sometimes indoors, or is in exceptionally damp or dry situations. Again, timber is often used in positions where one side is exposed to damp or even water (boats, for instance) and the other to relatively dry conditions.

Wooden parts liable to be exposed to the weather are usually well coated with paints and finishes, so that absorption of moisture is fairly well resisted over the comparatively short periods of actual exposure to wet. It should also be realized that paints and similar finishes, and even untreated wood, are much more resistant to the passage of *water* than they are to *moisture vapour*. It does not follow, therefore, that a piece of timber occasionally in contact with water necessarily experiences a greater moisture-content range in use than another apparently subject to considerably milder treatment.

The driest timber likely to be required is that destined for use in telephone exchanges and other electrical control rooms where a dry atmosphere is essential to the proper working of the delicate electrical apparatus. Here an average moisture content of about 8 per cent. will probably be found suitable.

The next driest situation is to be found in large blocks of offices or flats and departmental stores and shops where a high degree of central heat is in operation for a large portion of the

year. A moisture content of about 10 or 11 per cent. is correct for timber installed in such situations.

Then comes the more general case of moderate central heating, frequent open fires, and so on. All wooden articles kept in offices, living-rooms, &c., falling into this category should be manufactured from timber previously seasoned to a moisture content of about 12 per cent.

A slightly higher moisture content is permissible in positions where artificial heat is only rarely applied directly. Bedrooms, halls, staircases, landings and passages represent such conditions. A moisture content of about 13 to 14 per cent. is generally suitable for timber to be used in such places.

Timber intended for use in the construction of articles which are sometimes outdoors and sometimes indoors, but which are tolerably well protected from the elements and are well cared for, should be seasoned to a moisture content of about 15 per cent. Examples of articles of this type are motor vehicles and aeroplanes.

Also requiring about the same moisture content in their timber are articles permanently exposed to the weather on one face, but in contact with relatively warm and dry air on the other face. Examples of this type are window-frames, external doors, and boat timbers and decking.

Timber which will be exposed to the weather on one face and to unheated air on the other should be seasoned to a moisture content of about 16 per cent. Timber destined for use in poultry houses, small portable sheds, &c., would be most satisfactory if seasoned to this figure before manufacture.

Finally, we have the case of wooden articles exposed to the weather on all faces without any protection whatever. Gate and fence posts, gates and hoardings are often examples of this category. Here a moisture content of about 18 per cent. is suitable.

The above range of 8 to 18 per cent. moisture content may be said to cover all the requirements for seasoned timber and is applicable to most species of timber. Teak, as indicated earlier, would have to be seasoned to a content about 2 per cent. lower. African blackwood is another species having abnormally low equilibrium moisture-content values. No doubt there are others whose equilibrium characteristics are not yet known.

Timber which is continuously or almost continuously in contact with water obviously requires a higher moisture content, but such timber can hardly be termed seasoned.

Fig. 28 indicates suitable moisture contents for a variety of uses.

Plywood and laminated wood can be regarded as solid wood for all practical purposes in so far as the moisture content requirements are concerned. Unless very heavily impregnated with synthetic resin adhesives the equilbirium characteristics are not affected appreciably. It should be remembered, however, that if water-mixed glues are used in the assembly of plywood parts some absorption of water may well occur and in certain circumstances it may be advisable to overdry the plywood, veneers, etc., so that after glueing the moisture content will be about that normally required.

Absorption of Moisture by Dry Timber

A point which often occasions considerable anxiety to those handling dry timber—particularly kiln-dried timber—is the rate at which moisture may be absorbed. They are concerned lest the dry timber will pick up so much moisture on its journey to the job that the seasoning process will be partially undone, with the result that shrinkage will occur.

Usually there are no grounds for such anxiety, for it must be realized that timber will not wet more rapidly than it will dry. No one would expect a great deal of drying to take place in a stack of timber piled solid. Why then should bulk-piled dry timber be supposed to absorb moisture at such a rate? Moreover, it should be remembered that dry timber is usually not very far off the state where it would be in equilibrium with the air. Consequently, any interchange of moisture between the air and the timber is bound to be relatively slow. Of course, if there is a heavy fog moisture will be absorbed much more rapidly than in dry weather, but even so it will only be the outside pieces in a stack of timber that will be affected, and only the outer surfaces of these. The danger of exposing dry timber to rain is not so much from the moisture absorbed during the time the rain is falling as from the water that seeps in between the pieces, where it is trapped and can penetrate the wood at leisure.

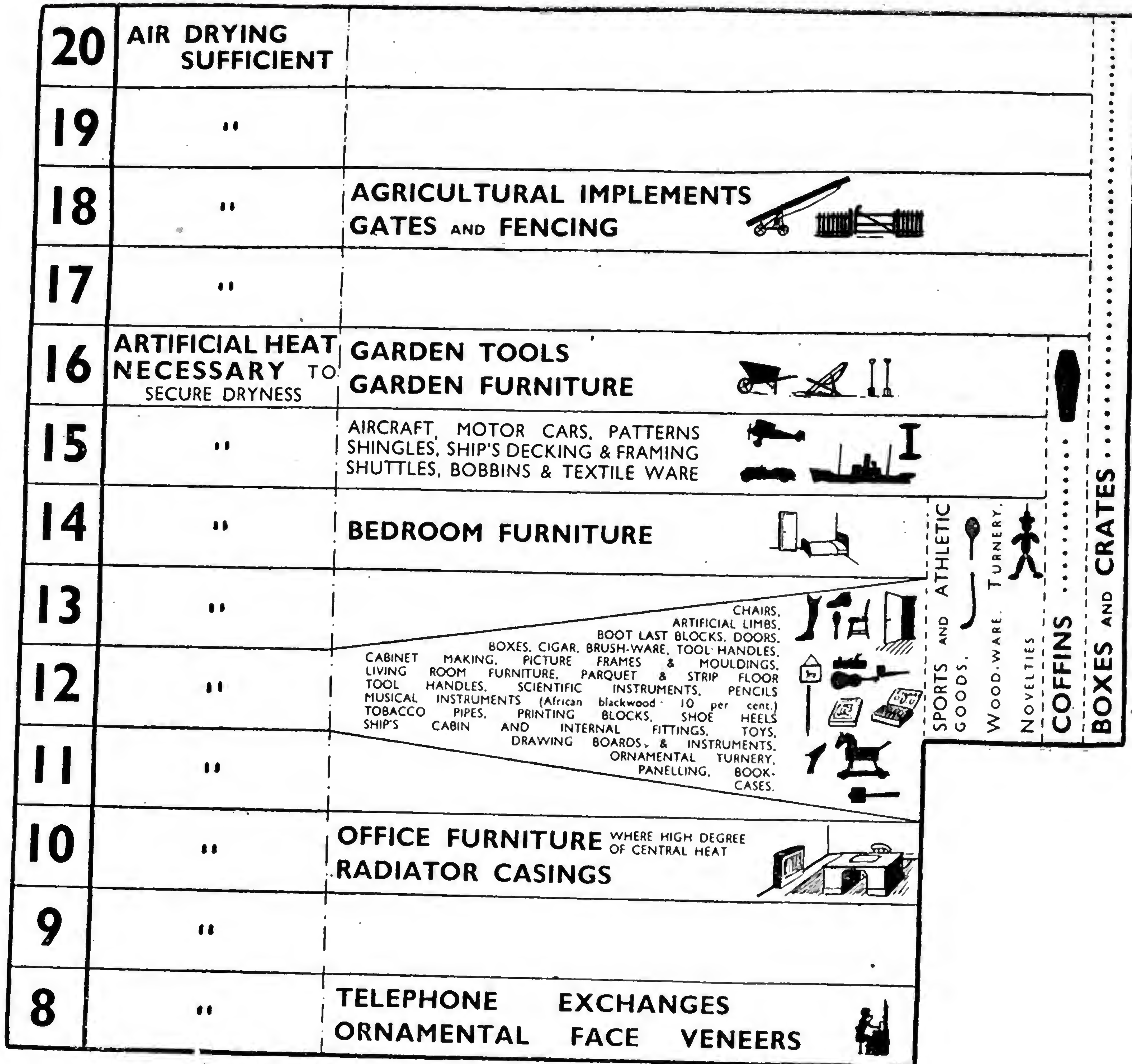


FIG. 28. Moisture contents attained by wooden articles in service.

Kiln-dried timber should always be piled closely and should be protected from rain with tarpaulins if piled in the open. If these simple precautions are taken, timber kiln-dried to, say, 12 per cent. moisture content, can be left in the open for a week or two without any serious pick-up of moisture—even in cold, wet weather.

The above remarks are intended to apply to boards, planks and scantlings. Very thin material like veneers absorbs moisture much more rapidly even though stacked in bundles. It is not usually a serious matter if veneers absorb moisture as they are very readily dried out again.

Rather a different state of affairs applies if stocks of kiln-dried timber are held in big quantities, because it is not usually possible to arrange for all the timber put into stock at a certain time to be used up within a reasonable period. Also the fact that the stock will be turned over continually when selecting material for various jobs implies that it will be exposed to the air much more freely than when left stationary in a solid pile.

A storeroom for kiln-dried material should therefore be maintained in a slightly warm condition. It should not normally be necessary to heat such a store during the summer months, because the rate of absorption of moisture will then be so slow that no serious pick-up is likely to take place. Generally speaking, ordinary workshop temperatures are more than sufficient for storing timber dried to a moisture content of about 12 per cent.

CHAPTER VIII

SEASONING PROBLEMS AND THEIR SOLUTION

REDUCING WARPING IN DRYING—RECONDITIONING—AVOIDING SPLITS AND CHECKS—AVOIDANCE OF STAINS AND FUNGUS ATTACK.

In the foregoing chapters most of the difficulties likely to arise in the seasoning of timber have been referred to, and in some cases methods of minimizing or avoiding such difficulties have been discussed.

In this chapter we shall deal with seasoning problems and their solution—wherever a solution is known—in particular. The reader will pardon a repetition of some earlier matter as it is perhaps appropriate to group it all together here under one head.

We have seen that most of the problems connected with the drying of timber are closely related to the fact that the withdrawal of moisture is accompanied by shrinkage and that the surface layers are necessarily dried in advance of the interior portion.

Therefore, in order to keep losses in drying to a minimum, shrinkage must be kept as small as possible and drying of the surface must not proceed too rapidly relative to the centre.

It may come as a surprise that the shrinkage of any one species of timber can vary, but there can be no doubt that it does vary very considerably, and such variations are by no means entirely accounted for by inherent differences in the wood. Figures for the shrinkages of common timbers are frequently tabulated, but never agree very closely with others obtained independently. The reasons for disagreement are to be sought for, among other things, in the manner in which the drying was carried out and the size of specimen measured. Obviously, since trees are roughly circular, measurements of the shrinkage made on rectangular specimens do not represent true radial or tangential shrinkages.

The larger the diameter of the tree and the smaller the size of the specimen, the more truly tangential or radial do the sides of the specimen become. But the smaller the size of the specimen the more difficult the relation of the results obtained to practice.

TABLE IV

RATIO OF TANGENTIAL TO RADIAL SHRINKAGE OF SOME COMMON TIMBERS

Plain-sawn material cut from timbers having a small ratio may be expected to 'cup' little in drying, while that cut from timbers having a big ratio will 'cup' badly unless restrained. Similarly 'diamonding' will be more pronounced in the latter.

Timber.	Tangential Shrinkage / Radial Shrinkage
Ebony	1·1
Scots pine (Red deal)	1·3
Obechi	1·5
Walnut	1·5
Sycamore	1·6
Norway spruce (White deal)	1·6
Birch	1·6
Hornbeam	1·6
Ash	1·7
Alder	1·7
Oak	1·8
Poplar	1·8
Chestnut (sweet)	1·9
Jarrah	2·0
Beech	2·1
Gurjun	2·2
Sapele mahogany	2·9

Reducing Warping in Drying

In any case, a precise knowledge of the shrinkage of timbers in drying is of academic value only. It is useful to know whether a timber shrinks a lot or a little, and it is also useful to know how the radial shrinkage compares with the tangential shrinkage, because the tendency to warp is largely bound up with this relationship. Table IV gives the ratio of tangential to radial shrinkage of some ordinary timbers.

A timber which shrinks a lot, or shrinks considerably more tangentially than radially, is going to require more care in drying than a small shrinker if warping is to be kept down. Knowing this, particular pains can be taken in stacking for drying—and if the timber is to be kiln-dried the schedule employed can be selected accordingly.

If timber is first air-dried and then finished off in a kiln or a warm store, it will be found that the shrinkage is less than if it had been kiln-dried from the green state. Also if high tempera-

tures are employed in kiln-drying, particularly in the early stages, shrinkage will be greater than if low temperatures are employed. Consequently, if it is important to keep warping to a minimum, air-cum-kiln-drying is the best plan, and if it is required to expedite matters somewhat so that kiln-drying from the green is indicated, then temperatures should be kept low (below about 120° F.) until the moisture content has fallen to, say, 25 per cent. Stepping up the temperature quickly from that point will not generally increase the shrinkage beyond the normal. Timbers containing much twisted grain should always be kiln-dried at low to moderate temperatures until the bulk of the moisture is removed. It will be found that the schedules recommended for timbers like elm and sapele mahogany maintain a low temperature for the major portion of the drying range.

It used to be thought that casehardening stresses influenced the shrinkage as a whole. Recent investigations indicate that they have little or no effect on the overall shrinkage.

The avoidance of excessive stresses in drying is therefore of no importance in so far as warping is concerned.

Timber is more likely to warp badly if dried in small pieces. This is probably because areas of twisted grain are more localized in a small piece, whereas in larger pieces other areas may be present which may pull in the opposite direction and so tend to counterbalance. Of course, timber takes longer to dry in plank form than, say, in squares, but the inevitable loss from warping will certainly be less in the case of planks. It is well known that a rectangular section of wood will tend to 'diamond' or become like a parallelogram in drying if the growth-rings run diagonally across the section. 'Squares' originally cut square will need a lot of trueing up to make them square when dry if the growth-rings are not running approximately parallel to one face of the square. Small pieces have also a bigger proportion of end-grain than larger and longer pieces and therefore a bigger loss from end-splits is liable to occur.

Reconditioning

Excessive warping and that peculiar form of distortion known as collapse can often be partially removed by a process known as reconditioning.

Reconditioning consists of subjecting the dry timber to saturated air at a temperature of about 100° C. (212° F.).

As it is of no real consequence if the air is super-saturated—that is, contains drops of water—the simplest way of producing the desired conditions is to use steam.

While steaming for reconditioning can be done in a kiln if auxiliary steam-jets are provided it is not likely to do the kiln any good, and consequently if any amount of reconditioning is contemplated a special chamber should be constructed. As the steaming process is carried out at atmospheric pressure, there is no need to make the reconditioning chamber steamtight. Almost any sort of box will serve the purpose. Only badly-warped or collapsed pieces are likely to benefit appreciably from reconditioning, so that the chamber need not have anything like the capacity of a kiln. Provided it is long enough to take the longest lengths handled, almost any size will suffice. If it is intended to treat pieces which are not collapsed but which are bowed, sprung, cupped or twisted, the timber should be stacked as neatly as possible having regard to their distorted shape,and the pile should be weighted with bricks or scrap iron. Live steam can be admitted at any point, and the chamber heated up as rapidly as possible. After a temperature of about 100° C. has been attained, the process should be continued for from two to eight hours, depending on the thickness of the timber. Two hours is usually sufficient for boards up to 1 inch thick, but four to six hours may be required for 2 inch planks.

When the treatment has been maintained for the requisite period the chamber can be cooled off by shutting off the steam. The doors of the chamber should not be opened till the temperature had fallen to, say, 120° F. (50° C.).

It will be found that reconditioning removes collapsed areas fairly effectively and swells the timber a little. Warping of other forms is also removed to some extent. The steam wets up the surface of the timber slightly, but most of this superficial wetting dries off in the cooling. In many cases, being confined to the surface it will rapidly dry off in a warm atmosphere.

It should be remembered that the worse the warping and collapse the more the recovery that may be expected. Even slightly distorted pieces will improve a little, but the recovery in that case is not sufficient to justify the expense and trouble involved.

Of the home-grown timbers the only common species that it generally pays to recondition are ash and elm. Beech can be treated sometimes, but is liable to split in cooling. Oak and chestnut do not respond very well. The softwoods do not usually warp or collapse very much, and in any case do not recondition very well.

Avoiding Splits and Checks

Ruptures of the fibres is usually brought about by the imposition of drying stresses, and while checks can be caused directly by what may be called pure shrinkage as, for instance, in knots or in the form of checks across the grain in timber exhibiting considerable 'longitudinal' shrinkage due to the presence of much twisted grain or so-called tension or compression wood, by far the majority of splits and checks are caused by disproportionate shrinkage occasioned by irregular drying. This is well demonstrated by the fact that splits are a comparative rarity in kiln-drying where the drying conditions are under control, but are very common in air-drying where drying is nearly always severe in the early stages.

Most people have come to regard a certain number of end-splits as almost inevitable in air-seasoning, whilst their occurrence in kiln-seasoning is an occasion for recrimination, and is taken as indicative of improper control of the drying.

Much can be done to prevent end-splitting in air-drying, however. The use of end-coating paints and cleats and other preventatives has already been described.

Timbers which show a tendency to split in drying should never be allowed to develop serious drying stresses. This is easier said than done in air-seasoning, but even here the use of thin piling-sticks will achieve a lot. In kiln-drying the humidity of the air is the determining factor. A very refractory timber requires high humidities until drying is well advanced. Recently, in drying roots used for tobacco pipes, the author found the only way to avoid splitting was to maintain a humidity of from 95 to 85 per cent. until the moisture content had fallen to below 30 per cent. Even then the humidity had to be kept up, and the drying was completed (12 to 14 per cent. moisture content) with the humidity of the circulating air still in the neighbourhood of 75 per cent. This was an extreme case, of course, but a good

many ordinary timbers require humidities of 80 to 85 per cent. till the moisture content has fallen to about 35 per cent.

It is sometimes possible to resort to certain expedients which minimize the effects of drying stresses. For instance, if large furniture squares are bored down the centre, drying takes place from within as well as from without, and the presence of the hole means that strains can be accommodated to some extent by deformation of the hole.

Avoidance of Stains and Fungus Attack

This matter has been fairly thoroughly discussed in earlier chapters, and it will suffice to summarize the position here by stating that rapid drying of the surface is the best safeguard against the staining fungi, that the same procedure is usually effective in arresting chemical staining due to enzymic action, and that moulds and staining fungi which develop in kiln-seasoning can be killed off with the aid of short steaming periods.

Dripping water sometimes causes nasty areas of discoloration. The remedy is obvious.

The loss that occurs in drying timber is enormous, and it is safe to say that a very large proportion of waste could be avoided if proper precautions were taken. Properly kept yards in which no scrap wood is allowed to accumulate ensure that wood-destroying fungi and insects are not encouraged to develop. Properly built stacks reduce the risk of staining, warping and mechanical damage. The use of appropriate sized piling-sticks and protection from wind and sun ensure that splitting and checking will not be excessive.

Moisture-content determinations in conjunction with sample pieces built into the piles mean that stocks are not held for seasoning longer than is required. Overhead charges and interest on capital are thereby reduced.

In kiln-drying the use of a modern and efficient kiln under the supervision of a capable operator enables quick drying to be accomplished with a minimum of seasoning degrade.

CHAPTER IX

THE FUTURE OF TIMBER DRYING

FINALITY IN DEVELOPMENT OF KILN-DRYING—CHEMICAL SEASONING—DRYING WITH SUPERHEATED STEAM—ELECTRICAL DRYING.

IF we dare to look into the future of timber-seasoning, we may guess that air-seasoning will continue to be used for many purposes where speed in drying is unimportant. We may also guess that any process which offers rapid drying facilities combined with reasonable cost of operation will make a big appeal and will come to be used more and more as time goes on. Drying with hot air as the medium for evaporating and removing moisture, as exemplified in a modern forced-draught kiln, may be said to have nearly attained the limit of efficiency. Any improvement which can be effected will be of a minor character only and can have no great influence on the rate at which timber can be dried.

A system which can show marked advantages over kiln-drying must therefore break away from the use of circulating hot air and employ some entirely different method. Several such systems have been proposed, and while none have reached the commercial stage of development, two or three have demonstrated their practicability.

Chemical Seasoning

One method consists of treating timber prior to seasoning in such a way that the drying process as carried out by ordinary ways is accelerated and simplified. This method, usually known as '**Chemical Seasoning**' or '**Salt Seasoning**', involves soaking green wood in an aqueous solution of some chemical, after which it is removed and dried in the ordinary way. The basic principle of this method is as follows: When a chemical is dissolved in water, the vapour pressure of the solution is lower than the normal vapour pressure of water. This means that whereas air which is less than saturated will evaporate water, it will not evaporate moisture from the solution we are discussing until the humidity is below the point at which it will be in equilibrium with the vapour pressure of the solution. This point will be considerably below 100 per cent. humidity. Saturated salt solution,

for instance, will remain unaffected until the humidity of the air has fallen to 75 per cent.

Therefore a piece of wood soaked in saturated salt solution can be placed in an atmosphere of 75 per cent. humidity without drying. But if only the outside layers are saturated with the solution, the centre will behave normally and will dry. We are then securing the desirable situation that the inside is drying in advance of the outside. The tendency for external splits to form is therefore very much reduced, though if the process is carried too far internal checks will occur. By suitably regulating the surrounding atmosphere drying can be accomplished without the imposition of severe stresses, and can be carried out much more rapidly than would otherwise be possible.

The same principle can be applied, using a mixture of organic vapours and water vapour, in which case hot gases can be circulated through timber in place of the air used in a kiln. After mixing with the water vapour drawn from the timber the two are condensed so that the organic liquid can be recovered, re-heated and passed through the timber stack again.

There may be a big future in this process, but as far as the author is aware the commercial possibilities have yet to be demonstrated.

Drying with Superheated Steam

Superheated steam has been used in the past as a circulating medium, but had very limited applications on account of the high temperatures involved. More recently a process has been developed whereby moderate temperatures have been possible by operating at reduced pressure. Considerable acceleration of the drying process would have to be shown to justify the costly operation involved.

Electrical Drying

The application of electricity to timber drying has engaged the attention of various investigators from time to time, and recent experiments have shown that extremely rapid drying can be achieved by the use of ultra-short waves. Some experimenters in the U.S.S.R. have been able to dry fairly large sections of timber in a few minutes by exposing them in a high frequency electric field, using a wave-length of about 5 metres.

The timber becomes heated internally so that the moisture flows readily to the surfaces. To translate a process of this type from the laboratory to the commercial scale is no easy task, but it would be unwise to assume that it will not be done before very long.

If it can be done at a reasonable cost, it will certainly revolutionize timber drying.

CHAPTER X

IN CONCLUSION

OWING to the great variations in texture and quality that occur within even any one species, the drying of timber must always remain to some extent an art. In other words, there are factors contributing to successful seasoning which cannot be pre-gauged exactly or expressed in customary symbols. The object of this book has been to assist in eliminating errors in drying practice which occur irrespective of the finer characteristics of timber. The factors which can only be sensed by the responsive, the artist or the skilled—call him what you like—are things of which it is impossible to write. The human element is therefore very real when dealing with the seasoning of wood. A good kiln operator, for instance, is of far greater importance than the very best drying equipment, and good kiln operators are born, not made. Nevertheless, given suitable apparatus and a sound grasp of the principles of drying, a conscientious operator need make no serious mistakes, nor fear to tackle the seasoning of any timber.

A good understanding of the part that shrinkage plays in drying should enable most drying troubles to be surmounted. Careful observation of the results obtained and of the methods used in drying one consignment of a particular timber should ensure greater success in subsequent consignments. Experience gained in this way is of more value than all the textbooks in the world, but the textbooks should be able to help by pointing the way to relevant observation, and by setting out a proper basis for experimentation. That, at least, has been attempted here.

Many attempts have been made to assess the seasoning characteristics of timber in readily catalogued measures. It would be so convenient to state that oak, for instance, shrank exactly so much in drying from one moisture content to another, and that the time required would be so much if such-and-such a drying schedule were used. But timber defies close analysis of this nature. The best one can say is that the shrinkage is usually so much but may vary between this and that limits, that the drying time required is about so many days or weeks. Statements purporting to give exact information on timber are misleading

and only cause trouble and disappointment. It may seem an admission of failure that research can offer no more precise guidance, but the fact of the matter is that research can offer tolerably accurate assistance, but such assistance would require so much qualification that the practical man would find it valueless. In the author's opinion the best compromise is secured when the experimenter remains alive to the practical aspect and endeavours to interpret his results in the light of the use to which they are likely to be put. The kiln-drying schedules quoted in this book by no means represent the best set of temperatures and humidities to be employed in drying any one load of timber. What they are meant to do is to serve as a basis from which to begin. If no previous experience in drying a certain class of timber has been acquired, the schedules given can be used at first. They represent reasonable treatment for average material with ordinary applications in view. Clearly the use that is to be made of the timber has a big bearing on the manner in which it can be dried. Timber dried in plank form to be used in plank form can be dried much more rapidly than if re-sawing is contemplated or likely. If it is to be left in the form in which it was dried, considerable variation in the manner in which the moisture is distributed is of no consequence. Similarly, the presence of moderate casehardening stresses is no objection. Large sections such as scantlings for sills or wagon stock need never be dried out thoroughly so that the centre is as dry as the skin, because a dry skin of considerable thickness is capable of withstanding any tendency to shrink or warp shown by the wetter core.

Thus familiarity with the quality of the timber and a knowledge of the use to which it is to be put enables much closer application of drying conditions, and may mean faster or slower drying than is possible with the 'recommended' schedule. Again, speed in drying and loss in drying must always be balanced one against the other, and nobody but the man on the job is in a position to strike that balance.

The case of kiln-drying schedules has been taken here because it is an excellent example, but the same reasoning can be applied in a lesser or a greater degree to nearly all matters connected with the drying of timber.

The behaviour of timber in use, the most suitable mois-

ture content at which to manufacture, and similar things, are governed by practical considerations of all kinds which influence procedure in handling. When it is stated that a moisture content of about 12 per cent. is desirable in woodwork destined for interior use, it does not follow that every individual will obtain the greatest economic satisfaction by adhering to such advice. It is, however, the best general advice that can be given without a detailed knowledge of particular requirements.

A textbook on timber drying performs one service at least that knowledge accumulated in the timber trade is nearly always unable to perform. Having no axe to grind and no subconscious desire to gloss the truth, its advice is unbiased and approaches the true facts as far as modern knowledge enables it to do.

Anyone who has had occasion to investigate new methods of timber drying stated by dozens of satisfied users as infinitely superior to the ordinary drying kiln, will have discovered that the timber trade is surprisingly ingenuous and is willing to believe that it is securing amazing advantages even where absolutely no evidence exists for such beliefs.

Because commercial firms do not as a rule make a practice of making extensive moisture-content tests, nor have the time or the facilities for carrying out other tests necessary to ascertain the behaviour of drying apparatus, they are apt to overlook serious defects, and such defects may not become apparent for some time. Even when they do become apparent, only too often the timber rather than the drying plant is held to be responsible.

This tendency to blame the timber rather than the seasoning has no doubt accounted for the lack of attention that the drying side has so often received in many commercial undertakings. While timbers vary enormously in their seasoning characteristics, their behaviour when seasoned is much more uniform in character. If a timber gives trouble in service by warping or shrinking or swelling or splitting, ninety-nine times out of a hundred the seasoning is at fault and any other timber handled in the same way would have given much the same trouble. This should perhaps be qualified by adding that timbers equally suitable from the utilization point of view may be expected to behave in much the same way in service, because, of course,

softwoods are generally more accommodating in the matter of 'movement' than hardwoods.

That the standard of timber-drying in this country is scandalously low will not be denied by those in a position to judge. Moisture-content determinations at any stage of drying or manufacture are the exception rather than the rule. With such scant attention paid to what is, after all, one of the most important aspects of timber utilization, it is not surprising that timber substitutes have made headway in recent years. Wood users are, however, now largely alive to the dangers associated with an insufficient knowledge of the properties of their raw material, and a greater interest is being taken in the need for correct seasoning. Such an interest at once demonstrates the unsuitability of air-dried timber for indoor use, and kilns and warm stores are appearing all over the country.

Hardly a new woodworking factory is erected to-day but that a properly designed kiln or store forms part of the equipment. Unfortunately, it is so often assumed that the proper drying plant is all that is required. It is not uncommon to hear of modern factories equipped with the latest machinery, including excellent drying kilns, that do not possess apparatus for the determination of the moisture content of wood. So many days in the kiln will look after the drying. But wood's competitors are not evolved by any such rule of thumb process.

Securing correctly seasoned timber should be just as essential as obtaining the high standard of finish now almost universally obtained in the machining operations.

One can rest assured that the time is not far distant when all timber operators of repute will become 'seasoning conscious', and it is to be hoped that this book may make some contribution, however slight, to such a state of affairs.

INDEX

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